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COMPUTER-AIDED EVALUATION OF TRANSPORT SYSTEMS

by

John R. Mumford

SEARCH AND CHOICE IN TRANSPORT SYSTEMS PLANNING

Volume XXII of a Series

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Cambridge, Massachusetts 02139

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Volume XXII of a Series

Prepared in cooperation with the
M.I.T. Urban Systems Laboratory

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Transport Systems Planning Division,
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Transportation Systems Division
Department of Civil Engineering
Massachusetts Institute of Technology
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ABSTRACT

Analysis of transportation systems for planning purposes is a process which includes several distinct steps. The analyst must search for an initial set of alternative actions, predict the impacts of each alternative, and evaluate the impacts according to one or more sets of assumed goals. He must then decide whether to implement the best action he has found thus far or to search for new alternatives. The process continues until the analyst finds a satisfactory alternative, or analytic resources (time, dollars) are exhausted.

A variety of sets of predictive models are currently available which predict the impacts of alternative transportation systems. However, little has been done to provide systems for evaluating these impacts and comparing the alternatives on the basis of the evaluations. Evaluation and comparison of alternatives is complicated for two reasons: the predictive models generate large quantities of impact data; and there are many different types of impacts which, though seemingly incommensurable, must be compared.

DODOTRANS is a problem-oriented computer language designed to permit an analyst to define actions, to predict the consequences or impacts of these actions, to evaluate the impacts conditional upon a statement of goals formulated as utilities, and to compare and rank the actions, based upon the results of the evaluations.

The purpose of this research was to design and implement additional capabilities for impact evaluation and comparison in the DODOTRANS system. Two guiding objectives in the development of these capabilities were: the inclusion of a variety of impact data types in the evaluation process; and the ability to perform parametric analyses over sets of actions, parameters, consequences and utilities. The information retrieval routines implemented to achieve these capabilities were

designed in a modular fashion. This makes possible the incorporation of new data types in the evaluation and comparison procedures whenever they become available. The retrieval routines also provide a necessary support for the future addition of general capabilities for graphical display or statistical analysis.

ACKNOWLEDGEMENTS

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The research described here builds upon results presented in earlier volumes in this series. The basic support for this earlier research was provided by the U. S. Department of Transportation, Office of Systems Analysis, with additional support for portions of the research provided by the General Motors Grant for Highway Transportation Research; by the Special Assistant to the Joint Chiefs of Staff for Strategic Mobility, Department of Defense; and by the Ford Foundation through a grant to the Urban Systems Laboratory of M.I.T.

Clearly, however, the opinions expressed herein are the author's and do not necessarily represent the views of any research sponsor.

I am deeply indebted to Professor Marvin L. Manheim, who has advised me and directed my research at M.I.T., and who has helped me to maintain a proper perespective at times when I became immersed in details and lost sight of the ultimate objectives.

I wish to thank Kenneth Follansbee for his able assistance in explaining the details of DODO, and for his suggestions for improving that system as part of this research.

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Special thanks are due to Connie Hood, whose fast and faultless typing was invaluable during the preparation of this report.

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1. BACKGROUND

1.1 Introduction

The Transportation Systems Division of the M.I.T. Department of Civil Engineering has been developing techniques for the analysis of transportation systems alternatives for the U.S. Department of Transportation. The task of the initial research project, entitled Search and Choice in Transport Systems Planning, was to design and carry out a prototype analysis which demonstrated the use of a computer-based analysis for predicting the equilibrium between supply and demand in a multimodal transportation system. [8,14][1] A follow-up research project, entitled Techniques for Searching Out Transportation Systems Alternatives, has extended and tested the techniques provided by the initial project.

Analysis of transportation systems for planning purposes requires the integration of a variety of analytical techniques. The demand for transportation must be predicted at several levels, ranging from the aggregate demand by all modes between regions separated by hundreds or thousands of miles, to detailed demands on specific routes or links in a transportation network. The supply of transportation services must be modelled at similar levels so that the demand for transportation can be related to the supply in a network equilibrium computation.

The generalized transportation "problem" concerns the prediction of the demand for transportation services, along with the corresponding

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[1] See Bibliography for references in brackets.

characteristics of supply which will satisfy that demand. Analyses which recognize the interdependence of supply and demand in transportation while searching for solutions to the transportation problem are called equilibrium analyses. [6]

The prototype analysis system developed by the Search and Choice research project is a problem-oriented computer language called TRANSET II. TRANSET II is one of many subsystems of ICES [11,12] (Integrated Civil Engineering System) developed by the M.I.T. Department of Civil Engineering for the solution of civil engineering problems. Other subsystems have been designed to solve problems in structural analysis and design, soils analysis, bridge design, and highway design.

A single run of the TRANSET II system of models produces large amounts of data. As anticipated, as TRANSET II was used for analyses of transport alternatives [13], it was found that analysis of one or several runs required laborious inspection of many pages of output. The evaluation of the consequences or impacts of even a single transportation alternative was very difficult due to the quantities of unstructured consequence data produced by the analyses. It was clear that additional capabilities were needed in TRANSET II to aid in the evaluation of impacts and the selection of the best alternative. Follansbee summarized the problem thus:[2]

1. An analysis of one transportation alternative produces large volumes of data.

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[2]Follansbee, K. G., A Prototype Information System for the Problem-Solving Process Model.

2. The development of a real-world transportation plan or policy which can be implemented requires more than just the prediction of impacts of one or two alternatives.

3. The differences and similarities of the predicted impacts for all alternatives should be determined to aid in the choice of an alternative.

4. The predicted impacts of each alternative are sensitive to changes in the exogenous parameters of the predictive models.

5. Different alternatives may accomplish the same goals but affect different groups in the region.

6. The degree to which any alternative achieves the goals is sensitive to the utilities (the parameters of evaluation), and the parameters of the predictive models. Thus, the need for sensitivity analysis compounds the problem of choice.

An example of a problem in transport systems analysis will be introduced here to illustrate some of the issues stated above. The actual analysis will be described in Chapter 4. The purpose of the example at this point is to indicate the nature and magnitude of the problems faced by the transport systems analyst, particularly in the evaluation process.

1.2 Example of Analysis of Transport Systems

Consider the problem of implementing a VTOL (Vertical Take-Off and Landing) air travel system in the megalopolitan area from Southern New Hampshire to Washington, D.C. extending inland to Appalachia. The problem is to choose a strategy for implementing VTOL service between a fixed number of terminals in three stages, resulting in direct flights between all terminals at the conclusion of the third stage.

The area of interest, commonly referred to as the Northeast Corridor, will be divided into five districts for this analysis. This is a very coarse breakdown, but it will suffice to demonstrate the problems and techniques encountered in transport systems planning. The five districts are defined below:

1. Washington and Baltimore
2. Philadelphia, Atlantic City, Wilmington, and Trenton
3. New York City
4. Hartford, New Haven, and Springfield
5. Boston, Worcester, and Providence

Four modes of travel will be considered in the analysis: auto, rail, conventional air, and VTOL.

Three strategies will be proposed for implementing a fully-connected VTOL system in three stages. The stages occur in 1970, 1975, and 1980, respectively. Figures 1.1, 1.2, 1.3 and are diagrams of the three strategies. Each line in these figures represents VTOL service in both directions between the districts connected by the line.

Each strategy consists of three actions, corresponding to the implementation of VTOL service over certain routes in the system. Since there are three strategies, there are nine actions which must be described and analyzed. In addition, it is necessary to define two additional actions which correspond to the system in 1960 and 1965 when no VTOL service is available. These actions are necessary because the predictive model used to predict population, per capita income, and regional output for each district in the system requires data from two points in time in order to predict data for a third point. The

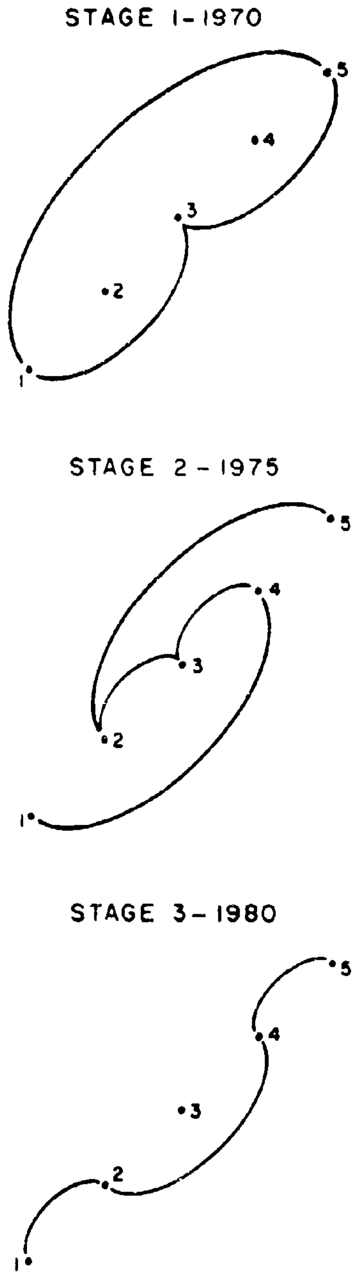

FIGURE 1.1: VTOL Strategy BIG3

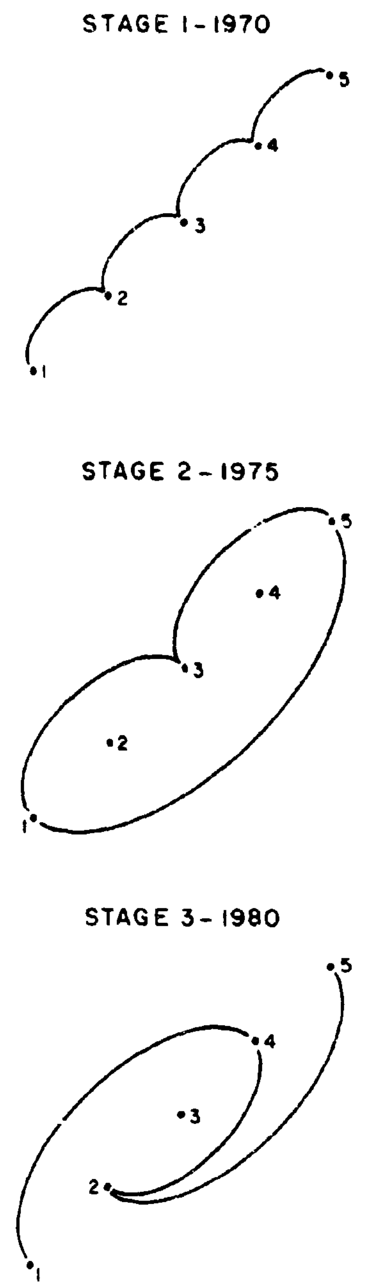

FIGURE 1.2: VTOL Strategy CHAIN

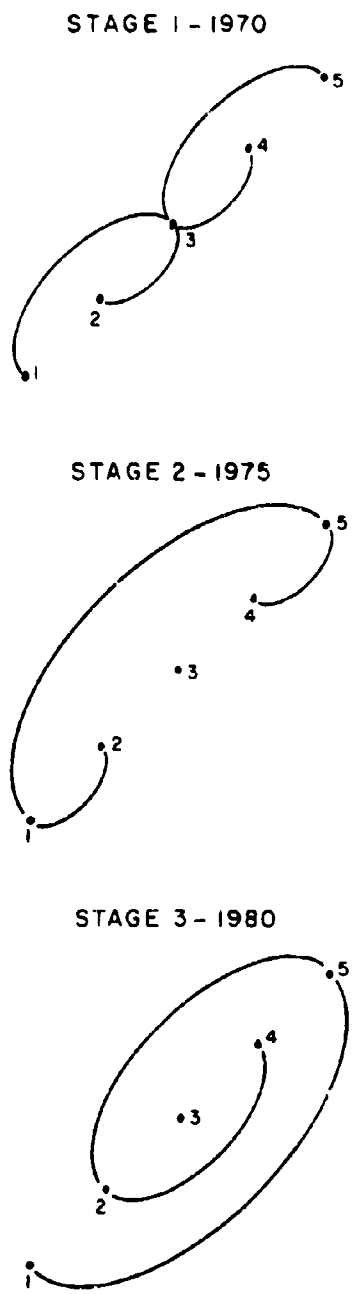

FIGURE 1.3: VTOL Strategy NY-AREA

population, per capita income and regional output of each district are impacts which must be evaluated for each stage of each strategy. The addition of actions in 1960 and 1965 which are essentially null actions (because no VTOL implementation occurs) permits the system of models to predict these impacts for the year 1970. Therefore, a total of eleven actions must be defined for this analysis.

1.2.1 Definition of Actions

A variety of data must be collected to define each action in the analysis. Each mode of travel is modelled as a series of links and nodes, connecting districts in a manner which approximates the route structure of each mode in the real-world system. The rail mode is modelled as a linear system with line haul links connecting adjacent districts only. The road system is modelled in a similar fashion with the addition of by-pass links which permit travelers to avoid passing through the center of the New York and Philadelphia districts. The air mode has direct line haul links connecting every district to every other district.

In addition to the links representing line haul travel, other links are included in the models which represent travel between the initial origin (home, office, etc.) and the terminal (for air and rail modes). Other links are included to model the movements through a terminal to board a train or plane. Similar links are included for travel at the destination district from the terminal to the ultimate destination. In summary, every segment of the total trip from one district to another which contributes a significant impact to the trip in terms of time,

money or any other measure is included as a separate link or links in the models of each mode. Links must also be added to represent the VTOL mode as service becomes available in each stage of each strategy.

Even though we are using a simplified five-district model of the Northeast Corridor, over 175 links are required to model all modes of travel. Each link must be described with respect to its length, capacity, and level of service. Level of service is described by a supply function which establishes a relationship between the travel volume and average speed on a link. The analyst must collect over 500 items of data in order to describe the 175 links used in the network model for each action.

The next step in the analysis is to collect data on each district for 1960 and 1965. The required data includes population, per capita income, and the holding capacity (or upper bound on population) for each district. The predictive models will predict these data for each of the VTOL stages. The district data for each action contains 15 items.

Finally, data which describes the operating characteristics of each mode must be collected. This data includes the fare and frequency of service over each route for each mode, the subsidy available to each mode, the tax rate imposed upon fares, and the fixed and variable costs incurred by each mode. Even though not all of these data apply to all modes (no direct subsidy to the road mode) there are over 200 mode data items to be collected for every action in this analysis. This task is made easier by the fact that much of this data is assumed to

be the same over several or even all of the actions. However, the potential exists for the collection of 11 × 200 = 2200 data items for this one category alone.

All of the data described above are inputs to the predictive models (with the exception, of course, of the district data for stages 1970, 1975, and 1980). Since a total of about 750 data elements are required to describe each action, the 11 actions in this analysis include over 8000 pieces of descriptive data. The potential difficulties in evaluating and comparing actions are apparent even before the consequences or impacts of each action are predicted.

1.2.2 Prediction of Consequences

The prediction of the consequences of each action is a straightforward procedure. The decisions regarding which consequences to predict are for the most part constrained by the design capabilities of the predictive models. The types of impacts generated by the predictive models for each action include the following:

1. Volumes of travel over each route by each mode.
2. Travel times over each route by each mode.
3. Volumes of travel over individual links in the network model of each mode.
4. Travel times over each link in the network model of each mode.
5. Relative measures of accessibility of each district for each mode.
6. District growth measures, including population, income, and total regional product.

The travel time and travel volume files alone include over 400 data items for each set of impacts. All told, over 500 impacts are predicted for each action. The 11 actions in this analysis include over 5500 impacts which must be compared and evaluated before the best strategy can be selected. Including the 8000 data items used to describe each action, there are over 13000 data items which must be evaluated before a strategy can be chosen.

1.2.3 Evaluation of Consequences

A vital step in the evaluation of the consequences of each action is the identification of all actors who are impacted by the consequences. Examples of actors impacted by a new VTOL system are the following:

1 - Travelers between various districts in the system

2 - Operators of the rail, VTOL and conventional air modes

3 - Residential areas affected by noise levels and land acquired for terminal construction

4 - Commercial interests affected by noise, pollution, or land-takings

5 - Political bodies at federal, state, and local level involved in selection of routes, levying of taxes on fares, awarding of subsidies, etc.

When all relevent actors have been identified, an impact matrix[3] can be constructed which arrays actors against impacts. Operations can be performed upon the impact matrix which will condense the

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[3] Manheim, M. L., et al., The Impacts of Highways Upon Environmental Values.

information and display the significant issues. The goal of these operations is a ranking of the actions. Four basic operations upon an impact matrix can be defined as follows:

1 - Define goal variables

2 - Compute values of goal variables

3 - Explore and compare values of goal variables

4 - Obtain "final" ranking

The definition of goal variables involves the aggregation of impacts into a measure which reflects more clearly the relative achievement of a particular goal. A complete goal variable definition is comprised of the impacts or lower order goals included as components, and the operation required to compute a value of the variable given values for the components.

Computation of the value of a goal variable involves the specification of a particular set of consequences and a particular set of links, routes, districts, or modes over which the evaluation is to take place. Impacts can be classified by the manner in which individual impacts are specified out of a large set of similar impacts. Inter-district travel times are specified by stating an origin district, destination district, and mode of travel. Link volumes are specified by stating an origin node and a destination node. District populations are specified simply by stating the district name. These classifications are called <u>data classes</u>. The descriptors indicating which routes, links, districts or modes are included in the evaluation are called the <u>range specification</u>.

Exploration and comparison of the values of a given goal variable is done by ranking all actions according to the values of a particular goal variable conditional upon a set of partial utilities. Parametric analyses over a range of parameters for the predictive models or a range of utilities are performed to determine the sensitivity of the rankings to uncertainty in the prediction and evaluation processes. If a goal variable is defined as a linear scoring function[4] with several components weighted to form a single total, one form of comparison or exploration would be to determine the values of the weights in the linear scoring function such that two or more alternatives had equal or nearly equal values of the goal variable.

The selection of a final ranking is done after many explorations and comparisons of the results of goal variable evaluation have been performed.

It should be stressed here that evaluation is not a one-pass procedure. The results of an evaluation may prompt the analyst to formulate new goal variables which must be evaluated and compared over a set of alternatives. He may even decide to create a new alternative for which consequences must be predicted and evaluated.

1.3 The DODOTRANS Language

The problem described in this chapter was analyzed with the aid of a new computer language called DODOTRANS. This language is the

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[4]See Chapter 2 for the definition of a linear scoring function.

result of several stages of software development which began with the TRANSET I system. [13] TRANSET I was created prior to the prototype analysis effort in 1967-68. It consisted primarily of a route selection model for single mode systems. TRANSET II extended TRANSET I to include demand prediction and route selection for a multimodal system. Follansbee was the originator of a language based on TRANSET II which was called DODO (Decision-Oriented Data Organizer). [3] DODO included all of the predictive capabilities of TRANSET II, as well as an evaluation capability based on the concept of a multidimensional goal fabric proposed by Hall and Manheim.[5] DODO permitted the user to structure his analyses so that a permanent record was maintained of the entire analytical process. Furthermore, DODO provided a limited set of capabilities for defining and evaluating goal variables which facilitated the evaluation of impacts of several transportation alternatives. The DODOTRANS language represents the current state of the system of models which began with TRANSET I. Numerous changes have been made from DODO in both the prediction and evaluation of the impacts of alternative transport systems.

The goal of the research reported here was to expand the evaluation capabilities of DODO. Subsequent chapters of this report describe the evaluation process in transport systems analysis, indicate the extent to which DODO automated that process and describe the extensions to DODO that were implemented as part of this research. Then these new

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[5] Hall, Frederick, and M. L. Manheim, Abstract Representation of Goal Structures.

capabilities are illustrated for the VTOL example outlined above. Finally, conclusions on the effectiveness of the new capabilities are made, including recommendations for future developments in DODOTRANS.

2. EVALUATION IN TRANSPORT SYSTEMS PLANNING

2.1 Introduction

This chapter contains a discussion of evaluation methodology, including a description of several evaluation techniques which have been used in transport systems planning. The evaluation capabilities provided by the TRANSET II and DODO computer languages are also discussed.

2.2 Evaluation Methodology

Let us consider the requirements which any evaluation technique used for transport systems planning must satisfy. A report prepared by the M.I.T. Urban Systems Laboratory for the National Cooperative Highway Research Program of the Highway Research Board includes a detailed discussion of the role of evaluation in highway location.[6] Though highway location analysis and the analysis of inter-city travel demands employ different techniques to predict impacts and evaluate alternatives, the general role of evaluation is common to both problems. Much of the discussion of evaluation methodology presented in this chapter is based upon a similar discussion in the NCHRP report.

2.3 Evaluation Strategies and Techniques

The NCHRP report distinguishes between determining an evaluation strategy and an evaluation technique. The broader of the two problems

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[6] Manheim, M. L., et al., The Impacts of Highways Upon Environmental Values.

is the determination of an evaluation strategy. This problem involves deciding how and from what information an impact matrix should be constructed. When these questions have been answered, the impact data available for evaluation is known. It then becomes a lesser problem to choose an evaluation technique which will operate upon the impact matrix to produce a ranking over a fixed set of actions. This research is concerned primarily with the problem of providing evaluation techniques for the transport systems analyst. The impact data available for evaluation has been determined for the most part by the predictive models in DODOTRANS.

An evaluation method (strategy and technique) must perform three functions. It must:

1. Produce a ranking of the alternatives.
2. Suggest areas of search for new alternatives.
3. Identify the crucial tradeoffs, i.e., present versus future impacts or the gains of one actor versus losses of another.

The evaluation method must also be able to reflect the preferences of several different interest groups or combination of interest groups. These groups may include the following:

1. The users of the transportation system.
2. The operators of the system.
3. Residential and commercial interested affected by the acquisition of land for rights-of-way, noise levels, and visual changes in their environment.

4. Political bodies at federal, state, and local levels.

The decision makers involved in the planning process may request that alternative actions be ranked according to each of several sets of preferences corresponding to different interest groups such as the ones stated above. They might also request that the preferences of several groups be combined into a single statement of preferences by assigning weights to the preferences of each group. An effective evaluation method should provide capabilities for the statement of preferences and modification of these preferences as the analysis of alternatives proceeds.

2.4 Different Evaluation Techniques[7]

A number of evaluation techniques have been used in transportation planning. Four of these techniques are listed below:

1. linear scoring functions
2. utility theory
3. cost-benefit analysis
4. goal fabric analysis

2.4.1 Linear Scoring Function

A linear scoring function technique assumes that impacts or indicators can be quantified and assigned a numerical weight. Rankings are produced by computing the weighted sum of all indicators for each

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[7] Manheim, et al., op. cit., Appendix B.

alternative. Linearity and value-wise independence of indicators are properties of linear scoring functions.

The major advantage of using a linear scoring function is that it provides an unambiguous measure of the total value of an alternative which can be applied to a wide range of alternatives in an efficient manner. The major disadvantages are the danger of inaccurate weights leading to the recommendation of bad alternatives, and the problem of neglecting all impacts which were not incorporated directly into the function.

2.4.2 Utility Theory

Utility theory assumes that a general relationship exists which relates individual impacts to their composite value. The linear scoring function is a special case of a general utility function; in the linear scoring function the relative utilities are constant. Utility theory has the same advantages and disadvantages as the linear scoring function. The difference in the two is simply the added accuracy of more complex functional forms provided by general utility functions, achieved with an added cost in the computation of the score for different alternatives.

2.4.3 Cost-Benefit Analysis

Cost-benefit analysis assumes that all impacts relevant to the ranking of alternatives can be assigned dollar values and combined into a total cost and total benefit for each alternative. This method has the advantage of allowing impacts to be added or deleted from the analysis in a straightforward manner. Disadvantages include

a tendency by analysts to omit impacts which are not easily assigned a dollar value in favor of those impacts which are more readily priced. There is also the danger of misinterpretation of the costs and benefits with respect to whose dollars are used and when they are payed out or received.

2.4.4 Goal Fabric Analysis

This technique is a method for structuring the goals of a system to show their relationships to one another. Four relations are defined: specification, means-end, value-wise dependence, and value-wise independence.

Specification refers to a set of goals which define explicitly a more general goal. The means-end relation signifies that one goal is a means to achieve another goal. Value-wise dependent goals are those which can be evaluated only in conjunction with other goals. Value-wise independent goals can be evaluated individually.

These relationships can be used to structure goals as an interwoven tree with the general goals at the top and the most specific goals at the bottom. The specific goals are directly related to the impacts which can be predicted for each alternative under consideration.

Evaluation proceeds from the base of the tree to the highest levels by checking for dominance of an alternative for all goals comprising a higher-level goal. When dominance cannot be established, the analyst must choose the best alternative in a subjective manner

based on the values of those goals which he feels are most important. He may be aided by the use of a linear scoring function employing a subset or all of the goals at a given level. He may also compare the intervals between alternatives on each goal to aid him in his decision.

Goal fabric analysis allows several evaluation techniques to be combined in a single analysis. Not all goals have to be quantified, as in the case of the other three techniques discussed above. Its relational and hierarchical structure also provides a means for graphically displaying the structure of the goal fabric.

Disadvantages of goal fabric analysis include the difficulty of evaluating the performance of alternatives on higher level goals and the difficulty in specifying tradeoffs between goals which are not directly related to the same higher level goal.

2.5 Evaluation in TRANSET II and DODO

Chapter 1 has indicated the general procedure required for defining actions and predicting their consequences in DODOTRANS. These procedures were very similar in TRANSET II and DODO. Evaluation techniques have changed significantly from TRANSET II to DODOTRANS, however.

2.5.1 TRANSET II Evaluation Capabilities

The TRANSET II user was limited to a number of "canned" routines which computed quantities such as consumer surplus, accessibility, gross revenue, and total user cost. The only flexibility provided for the analyst was the specification of a partial utility in terms

of a dollar value assigned to time and an estimate of waiting time as a function of the frequency of service. The only goal variables the TRANSET II user could evaluate were those provided by these routines, namely: consumer surplus, gross revenues, operating balances, and accessibilities.

2.5.2 DODO Evaluation Capabilities

The DODO user was able to proceed further in the evaluation process. He could define a series of goal variables, i.e., variables whose values provide an indication of how well a particular action achieves predetermined goals, as algebraic combinations of variables from the set of basic consequences generated by the predictive models. A set of goal variable definitions was called a goal fabric.[8] The generalized form of goal fabric definition in DODO is the following:

```
DEFINE GOAL FABRIC 'gfname'
'goal_1' = [Operator] [Operand 1] [Operand 2]
'goal_2' = [Operator] [Operand 1] [Operand 2]
                 .
                 .
                 .
STOP DEFINITION OF GOAL FABRIC
```

where 'gfname' is an arbitrary name assigned by the analyst to the goal fabric,

'$goal_1$', '$goal_2$', ... are arbitrary names assigned by the analyst to

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[8]Hall, Frederick, and M. L. Manheim, Abstract Representation of Goal Structures.

the goal variables,

the available operators are

MINIMUM

MAXIMUM

TOTAL

AVERAGE

PRODUCT

and the available operands are

TRAVEL TIME

FARE

FREQUENCY OF SERVICE

TRIPS

During the evaluation process, all of the operands must be further defined by specifying an origin district, destination district and mode of travel. This type of data is called <u>interdistrict data</u>.

The MINIMUM, MAXIMUM and TOTAL operators require a single operand, while AVERAGE and PRODUCT require two operands. Examples of goal variable definitions in DODO are

'TOTTRIP' = TOTAL TRIPS

'MINTIME' = MINIMUM TRAVEL TIME

'REVENUE' = PRODUCT OF FARES AND TRIPS

The DODO user can evaluate a goal fabric for a given set of consequences by specifying the goal variables to be evaluated a' their respective <u>ranges of evaluation</u>. For interdistrict data, the range of evaluation is specified by indicating which origin districts, destination districts, and modes are in the range. An example of evaluation in DODO is shown below:

```
EVALUATE GOAL FABRIC 'VTOL', CONSEQUENCES 'C1'
    'TOTTRIP' FOR ORIGIN 'BOSTON' DEST 'NY' MODES ALL
    'MINTIME' FOR ORIGINS ALL DEST ALL MODE 'AIR'
    'REVENUE' FOR ORIGINS ALL DEST ALL MODES EACH
STOP EVALUATION
```

This command sequence in DODO evaluates goal fabric VTOL, previously defined by the analyst, for consequence set C1, which was previously predicted by the analyst using other DODO commands. Each of the goal variables specified must be part of goal fabric VTOL. Evaluation of TOTTRIP results in the total number of trips by all modes between Boston and New York. Evaluation of MINTIME determines the minimum travel time over all routes for the air mode. Goal variable REVENUE is actually evaluated <u>several</u> times. Each evaluation computes the gross revenue (defined as the product of fares and trips) over all routes for a <u>single mode</u>. The number of evaluations required is determined by the number of modes in the system.

Thus the DODO user has a more general evaluation capability at his disposal than the TRANSET II user did. He can search out minimum, maximum, and average values of certain impacts over a variety of ranges, as in the case of goal variable MINTIME above. He can also compute totals of impacts over various ranges, as in the case of goal variable TOTTRIP. Finally, he can combine certain impacts, such as fares and trips in goal variable REVENUE, into a single goal variable which can be evaluated for different ranges.

2.5.3 Limitations of DODO Evaluation Procedures

DODO includes the beginning of a general computer-based evaluation capability for transport systems analysis. However, experiments conducted with the DODO evaluation commands revealed several limitations:

1. The results of the evaluation of a goal fabric were not stored in the DODO information files. If several comparisons were performed upon the same evaluation results, the evaluations had to be performed again for each comparison.

2. The operators provided for goal variable definitions were inadequate. Specifically, a division operator and a sum operator which accepts more than two operands are useful capabilities which were not available in DODO. The division operator would be useful to compute ratios of impacts to determine load factors on vehicles, the percent of capacity being used on line haul links, etc. The sum operator is

necessary if a linear scoring function is to be included as an evaluation technique.

3. All operands were implicitly assigned equal weights during goal variable evaluation. A utility function which assigns different weights to each operand in a goal variable would allow an analyst to incorporate a statement of preferences into the evaluation process. The most basic form of utililicy function (and the easiest to implement) would be a linear scoring function consisting of a vector of constant weights. The form of evaluation of a goal variable using the sum operator would become:

$$G = \sum_i W_i X_i$$

where G is the computed value, and W_i is the weight assigned to the i^{th} operand X_i. With such a utility function, sensitivity analysis upon the assumed goals could be accomplished by varying the weights.

4. Constant data could not be specified as an operand in the definition of a goal variable. This capability would allow a constant term to be added to a linear scoring function. It would also allow ratios to be formed in which a particular

impact was compared to a standard value specified by the analyst.

5. Only interdistrict data (as defined above) could be specified as operands in goal variable definitions. The analyst should be able to address many other types of data generated by the predictive models or specified during the definition of actions. Examples of new data classes which could be added are:

   Link data - link volumes, link speeds

   Mode data - mode subsidy, mode tax rate

   District data - district population, district accessibility

   The three new data classes listed above contain many data items which should be made available to the analyst in evaluation procedures.

6. The analyst could not rank actions based upon their relative goal performance. A capability for ranking a goal variable over a set of actions, consequences, prediction parameters or utilities would facilitate the choice of the best action. This capability would permit parametric analyses to be performed which would indicate how sensitive the ranking of actions was with respect to uncertainty in the estimation of the parameters for the predictive models. The sensitivity of

the rankings to the preferences indicated by the utilities could also be explored with this capability.

Each of the limitations noted above has been remedied by this research and incorporated into DODOTRANS. The details of the new capabilities are outlined in Chapter 3.

3. EVALUATION AND COMPARISON CAPABILITIES IN DODOTRANS

3.1 Introduction

The new capabilities for goal fabric definition, evaluation, and comparison are presented in this chapter. The details of the command language are found in the DODOTRANS Users' Manual*.

3.2 Definition of Evaluation Terminology

It is necessary at this point to define a number of terms which will be used throughout this chapter. Some of the terms have been defined previously, but they will be restated here. The reader will be familiar with them as they appear in subsequent sections of this report.

Goal Variable - A goal variable is a combination of impacts or consequences chosen because its value reflects the ability of an action to achieve a particular goal or goals. The general structure of the definition of a goal variable is an operator followed by one or more operands.

Goal Fabric - A goal fabric is a series of goal variable definitions.

Operator - An operator in a goal variable definition specifies the operation to be performed upon the operands in order to compute a value for the goal variable.

Operand - An operand in a goal variable definition may be either a basic consequence variable generated by the predictive models or an immediate datum (a constant).

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*Ruiter, Earl R. ICES DODOTRANS Engineering Users' Manual, R69-42 Department of Civil Engineering, M.I.T., Cambridge, Massachusetts, July, 1969.

Data Class - The data class of a goal variable is determined by the type of identifiers required to completely identify a member of the class. For example, the interdistrict data class is characterized by the fact that complete identification requires specification of the origin district, destination district, and mode of travel. Other data classes which have been made available for evaluation by this research are the link, mode, and district data classes. Link data is identified by stating the numbers of the origin and destination nodes. Mode data is identified by specifying the name of the mode. Similarly, district data is identified by specifying the name of the district. All operands in a goal variable definition must be from the same data class so that they can be evaluated over a common range of evaluation.

Range of Evaluation - The range of evaluation or range specification refers to the information which must be provided during the evaluation of a goal variable to indicate which specific values of the operands are to be included in the computation. The format of the range specification is different for each data class. The range of evaluation of an interdistrict goal variable includes a set of routes. The range for a link goal variable includes a set of links. Similarly, ranges of evaluation for district and mode goal variables are comprised of sets of districts and modes, respectively. Examples of ranges of evaluation for each data class are given below.

Interdistrict data

```
FROM ORIGIN 'BOSTON' TO DEST 'NY' BY MODES ALL
FROM ORIGINS ALL TO DEST ALL BY MODE 'AIR'
```

Link data

```
FROM NODE 2301 TO NODES ALL
FROM NODES ALL TO NODE 3003
```

District data

```
FOR DISTRICT 'HARTFORD'
FOR ALL DISTRICTS
```

Mode data

```
FOR MODE 'RAIL'
FOR ALL MODES
```

Utility Function - The purpose of a utility function is to include a statement of preferences in the evaluation process. A utility function in this chapter refers to a vector of constants used to weight the operands in a goal variable definition during computation. This form of utility is a special case of the general

utility function in which the utility assigned to each operand of the goal variable is constant for all values of the operand.

Now that we have defined several terms used in the description of the new capabilities implemented as part of this research, let us proceed to examine those capabilities.

3.3 Goal Fabric Definition

The definition of goal variables has been expanded to include link, mode, and district data. A complete list of the operands provided for each of these new data classes appears in Appendix I. The introduction of three new data classes requires that the data class must be specified in the goal variable definition. Examples of goal variable definitions in DODOTRANS are shown below:

'AVE-D-AC' = AVERAGE DISTRICT ACCESSIBILITY, UNWEIGHTED
'BTLENECK' = MINIMUM LINK SPEED
'MAX-SUB' = MAXIMUM MODE SUBSIDY

Goal variable AVE-D-AC is evaluated by summing up the accessibility for all districts in the range of evaluation and dividing by the number of districts. BTLENECK is evaluated by searching the entire range of evaluation for the link with the minimum speed for vehicles traveling over the link. When this goal variable is displayed it is necessary to print both its value and the description of the link at which the value occurred. MAX-SUB is evaluated by searching the range of

of evaluation for the mode with the maximum government subsidy. Again the value of this goal variable must be accompanied by the mode for which the value was found. In each of the three goal variables listed above, the computation of the result includes multiplication by a utility vector consisting of a single constant. The obvious choice for the utility in each case is 1.0.

The reason for distinguishing between data classes in goal variable definitions is that the range specification used during evaluation varies with the data class. Appendix I lists the form of range specification for each data class.

Two new operators have been provided for goal variable definitions. The QUOTIENT operator requires two operands. It is used in the same manner as the PRODUCT operator. The SUM operator replaces the TOTAL operator. It may be used with any number of operands, provided that they are all of the same data class. The SUM operator is used as follows:

```
'USERCOST' = SUM OF INTERDISTRICT DATA,
    5.0
    FARE
    FREQUENCY
    TRAVEL TIME
END LIST OF OPERANDS
```

Goal variable USERCOST attempts to measure the total cost of a trip to a user in terms of the fare, frequency of service, and travel time of the trip in a linear scoring function. USERCOST is evaluated by performing the following computation:

$$USERCOST = \sum_i \sum_j \sum_k [(U_1*5.0) + (U_2*FARE_{ijk}) + (U_3*FREQ_{ijk}) + (U_4*TT_{ijk})]$$

where $i = i^{th}$ origin district,

$j = j^{th}$ destination district,

$k = k^{th}$ mode,

$U_1 \ldots U_4$ = utilities,

5.0 = constant operand,

$FARE_{ijk}$ = fare from origin i to destination j by mode k,

$FREQ_{ijk}$ = frequency of service from origin i to destination j by mode k,

and TT_{ijk} = travel time from origin to destination j by mode k

The values of i, j, and k used in the evaluation of USERCOST are determined by the origins, destinations and modes in the range specification.

3.4 Utility Function Definition

A utility function consisting of a linear scoring function has been added to DODOTRANS. The utility is defined with n values or weights. Its purpose is to weight the operands during the evaluation of a goal variable with n operands. Examples of utility function definitions follow:

UTILITY 'I-1', 1 VALUE, 1.0

UTILITY 'USER-1', 4 VALUES, 1.0, 1.0, -1.0, 0.04

UTILITY 'USER-2', 4 VALUES, 1.0, 1.0, -1.0, 0.08

UTILITY 'USER-3', 4 VALUES, 1.0, 1.0, -1.0, 0.16

If utility USER-1 were used to evaluate goal variable USERCOST, the resulting computation would be of the form

$$\text{USERCOST} = \sum_i \sum_j \sum_k [(1.0*5.0) + (1.0*\text{FARE}_{ijk}) - (1.0*\text{FREQ}_{ijk}) + (0.04*\text{TT}_{ijk})]$$

Note that negative weights can be assigned to utilities. This capability is significant because it allows the analyst to model any first degree polynomial by constructing an appropriate utility function.

3.5 Goal Fabric Evaluation

There are two basic changes in the goal fabric evaluation procedure as implemented in DODOTRANS. The first change is that utilities must be specified prior to the evaluation of a goal variable. Once a utility function has been specified during an evaluation procedure, it is used in subsequent evaluations until a new utility function is named. If the number of operands in the goal variable being evaluated does not equal the number of weights in the current utility function, an error message is printed, the goal variable is ignored, and evaluation proceeds with the next goal variable.

The second change in the evaluation procedure is that the results are not printed immediately after evaluation takes place. This was

done because the analyst does not always want an immediate listing of all of the results of an evaluation. The volumes of output would be particularly undesirable in a time-sharing environment where output is generally displayed at a typewriter console with a very slow printing speed. A WRITE EVALUATION RESULTS command has been provided to print out any portion of the evaluation file. See Figure 3.1 for an example of the output of evaluation results. All evaluation results are stored in the DODOTRANS information files. An example of goal fabric evaluation follows:

```
EVALUATE GOAL FABRIC 'VTOL', CONSEQUENCES 'C2'
    UTILITY 'I-1'
        'MAX-SUB' FOR ALL MODES
        'BTLENECK' FOR LINKS ALL
    UTILITY 'USER-1'
        'USERCOST' FOR ORIGIN 'NY' DEST 'BOSTON' MODES ALL
    UTILITY 'USER-2'
        'USERCOST' FOR ORIGIN 'NY' DEST 'BOSTON' MODES ALL
    UTILITY 'USER-3'
        'USERCOST' FOR ORIGIN 'NY' DEST 'BOSTON' MODES ALL
STOP EVALUATION
```

The evaluation proceeds in the following manner:

1. First the general EVALUATE command states that all subsequent goal variables are to be found in goal fabric

WRITE EVALUATION RESULTS FOR GOAL FABRIC 'VTCL-VAL' -
VARIABLE 'PASSMILE', UTILITIES ALL, CONSEQUENCES ALL

GOAL VARIABLE NAME	UTILITY FUNCTION NAME	CONSEQUENCE FILE NAME	VALUE	RANGE SPECIFICATION
PASSMILE	1-2	NOVTOL63	17364289.00	FOR ALL LINKS
PASSMILE	1-2	NOVTOL65	10082064.00	FOR ALL LINKS
PASSMILE	1-2	RIG3-1	25330449.00	FOR ALL LINKS
PASSMILE	1-2	RIG3-2	33362626.00	FOR ALL LINKS
PASSMILE	1-2	RIG3-3	39707872.00	FOR ALL LINKS
PASSMILE	1-2	CHAIN-1	26604849.00	FOR ALL LINKS
PASSMILE	1-2	CHAIN-2	36661569.00	FOR ALL LINKS
PASSMILE	1-2	CHAIN-3	42336258.00	FOR ALL LINKS
PASSMILE	1-2	NY-AREA1	26506392.00	FOR ALL LINKS
PASSMILE	1-2	NY-AREA2	34516082.00	FOR ALL LINKS
PASSMILE	1-2	NY-AREA3	40656060.00	FOR ALL LINKS

EJECT

FIGURE 3.1: Example of WRITE EVALUATION RESULTS Command

VTOL, and that the values of all operands are to be retrieved from consequence set C2.

2. Utility I-1 is specified prior to the evaluation of goal variables MAX-SUB and BTLENECK, each of which has but one operand in its definition.

3. Next goal variable MAX-SUB is evaluated for all modes. The maximum government subsidy for all modes defined in consequence set C2 is found and stored in the DODOTRANS evaluation files. The name of the mode is also stored.

4. Goal variable BTLENECK is evaluated next. The link with the minimum speed is found and the value (speed) is stored, along with the description of the link for which the value was found.

5. Utility USER-1 is specified prior to the evaluation of goal variable USERCOST. Since fares in DODOTRANS are expressed in dollars and travel times are expressed in minutes, the utility values of 0.04 applied to travel time and 1. [illegible]ed to fare results in a valuation of time of .04 dollars per minute. This corresponds to $2.40/hour.

6. Goal variable USERCOST is evaluated with utility 'USER-1' for each mode between New York and Boston.

7. Utility USER-2 is now specified. This utility values time at $4.[illegible]0/hour.

8. Goal variable USERCOST is evaluated over the same range as before, but with the new utility USER-2.

9. Utility USER-3 is specified, assigning a value to time of $9.60/hour.

10. Finally, goal variable USERCOST is evaluated over the same range with utility USER-3.

11. The STOP command terminates the evaluation process.

Note that a parametric analysis of goal variable USERCOST has been performed with respect to the value of a traveler's time for consequence set C2. If this evaluation were repeated for all consequences predicted for all alternative actions in an analysis, then the sensitivity of the ranking of the actions with respect to the value of time could be explored by examining goal variable USERCOST over all consequences.

3.6 Goal Fabric Comparison

The comparison of goal fabrics is a capability which was present in DODO in a very limited form. It has been greatly expanded in DODOTRANS.

3.6.1 Base Specifications

After the initial COMPARE command has been given to indicate which goal fabric is to be examined, the analyst must declare the base specifications. Base specifications must be declared so that computation of deviations from a base value chosen by the analyst can be performed. The ranking of actions does not depend upon the choice of base specifications. Base specifications include an action, parameter, consequence, and utility. If a base consequence is specified, the

corresponding action and parameter are retrieved from the DODOTRANS information files. The goal variable being compared must have been evaluated for the base specifications or the comparison will be terminated.

3.6.2 Set Specification

The next step in the comparison procedure is to specify a set over which the comparison will take place. A set is merely a list of names which can be referred to by a single name. The set may be either a set of actions, parameters, consequences, or utilities. Whichever set type is chosen, the corresponding base element will be varied by replacing it with members of the set as the comparison proceeds. All other base specifications remain constant.

3.6.3 Ranking Specification

The analyst has the option of ranking goal variable valuations in either descending or ascending order. If no specification is given, descending order is assumed. However, once a ranking subcommand has been given the ranking order is used until another ranking subcommand or a new COMPARE command is processed by the system.

3.6.4 Goal Variable Specification

After the base specifications and a set have been specified, the goal variable name and range of evaluation is specified. The form of specification is identical to the form used in evaluation.

Comparison proceeds as the evaluation file is searched for values of the goal variable which were obtained from the actions, parameters, consequences, utilities and range of evaluation specified in the

command. When all values have been retrieved, the tabular output is prepared which includes the values retrieved, the ranking of the values, the difference of each value from the base (both absolute and % difference), and the difference between each value and the maximum and minimum values. The example problem described in Chapter 4 contains many examples of output from the COMPARE GOAL FABRIC command.

4. EXAMPLE OF EVALUATION IN DODOTRANS

4.1 Introduction

This chapter describes the evaluation and comparison of impacts for the three alternative VTOL strategies outlined in Chapter 1. The definition of actions and prediction of their consequences are not described in detail here. They have been included in Appendix II, however. The intent of this chapter is to focus upon the use of the new capabilities for the evaluation and comparison of goal fabrics which were implemented as part of this research. The sequence of the discussion parallels the sequence of the analyses which were performed to evaluate and compare the three VTOL strategies described in Chapter 1. The reader can follow the analysis in the computer listings included at the end of this chapter. The listings have been annotated to include the number of the subsection of this chapter which describes each portion of the analysis.

4.2 Construction of a Goal Fabric

Evaluation of the VTOL strategies uses the goal fabric technique described earlier. The construction of a goal fabric involves the identification of combinations of impacts which measure the goal performance of an action. Goal variables in the goal fabric should be defined in terms of impacts which 1) affect the relevant actors in the system, and 2) are likely to vary significantly with the alternative strategies being analyzed. The impacts chosen for goal variable definitions should be outputs of the predictive models in

DODOTRANS whenever possible, as opposed to impacts specified as inputs by the analyst. For example, subsidies to each mode are undoubtedly a significant impact reflecting upon both the operators of each mode and the federal government. However, since direct subsidies are direct inputs to the DODOTRANS models, a more interesting goal variable would be the operating balance of each mode.

The first step in construction of a goal fabric is to identify the relevent actors. For this example, three relevent actors will be identified. There are many more than three actors in most transport systems problems (including this example), but the three chosen here will be sufficient to demonstrate the methodology of evaluation using DODOTRANS. The three actors identified in this analysis are:

1. Users of the transportation system
2. Operators of each mode (except auto)
3. Federal government

The impacts of the system on users is reflected in performance measures such as travel times and frequency of service. They are also affected by fares and taxes applied to fares.

Impacts which affect the operators include revenues, operating costs, government subsidies and tax rates on fares.

The federal government is affected by government subsidies to operators and taxes collected on fares.

All three actors are affected by the total amount of travel throughout the system. They all are also affected by the accessibility of each district to travel by each mode.

consequences corresponding to the three VTOL strategies with three actions in each strategy.

4.7 Comparison of Goal Fabric VTOL-VAL

Let us explore the valuations of goal fabric VTOL-VAL for consequence set VTOL-SET. After giving the general COMPARE GOAL FABRIC command, we specify base consequence BIG3-1, base utility I-1, and consequence set VTOL-SET. The choice of a base consequence is an arbitrary one.

First we compare goal variable BTLENECK over consequence set VTOL-SET. The values will be ranked in descending order so that the alternative with the highest minimum link speed will be ranked first. Since three time periods are represented by the consequences in set VTOL-VAL, we might expect the general increase in the demand for travel as a function of time (due to positive growth in the population of the region) to cause the actions in 1970 to be ranked higher than the actions in 1975 and 1980. The table of comparison results confirms this assumption. Examination of the ranking of the values of BTLENECK shows that the top three values correspond to 1970, the next three values to 1975, and the last three to 1980.

The ranking is not the most useful information found in the comparison, however. Note that the actual values of BTLENECK range from a high of 2.03 to a low of 1.46. Since these values represent speeds in miles per hour, it appears that a portion of the transportation system is heavily congested in all stages of each strategy. The

WRITE EVALUATION RESULTS command will be used later to determine the location of these congestion points.

Goal variable CONGEST is examined next over consequence set VTOL-SET. The ranking is computed in ascending order. The results of this comparison also reveal that the ranking of actions is directly related to the time period in which the action occurred. The values for 1975 are approximately 8% higher than the values of 1970, while the values for 1980 are approximately 20% higher. The alternative actions in a given stage are generally within 1% of each other with respect to the values of CONGEST. A notable exception is stage 1 of strategy BIG3. The omission of VTOL service for the Philadelphia and Hartford districts has an adverse effect on the maximum link volume for stage 1, which seems to disappear in later stages when all districts are served by VTOL.

A comparison of the average district accessibility reveals a general improvement in this goal variable over time for each strategy. Stage 1 of strategy BIG3 again performs poorly because of its limited VTOL service.

A closer examination of the rankings for the three comparisons performed thus far reveals that no strategy ranks consistently ahead of the others for all three stages. In fact, the ranking for goal variable AVE-D-AC indicates that strategy CHAIN is preferred in stage 1, strategy NY-AREA is preferred in 1975, and strategy BIG3 is preferred in 1980.

Examination of the percent differences from the base value for each of the three comparisons reveals that the differences between the strategies tend to become smaller in later stages.

Finally we compare the gross revenues for each mode over consequence set VTOL-SET. The results follow the pattern of previous comparisons. Revenues generally increase with time. The initial stage of strategy BIG3 generates a much lower revenue for VTOL than the other two strategies in the same stage. The rankings for the air, road, and rail modes are very similar to each other. However, they differ substantially from the ranking for VTOL. This is probably true because the range of service, i.e. routes served, does not change over time for modes other than VTOL.

4.8 Closer Examination of BTLENECK and CONGEST

The WRITE EVALUATION RESULTS command is used next to determine the location of the low speeds and high volumes which were pointed out by the evaluation of goal variables BTLENECK and CONGEST. The low speeds located with the BTLENECK goal variable are VTOL and rail terminal links. Their values do not necessarily represent congestion in the system at the terminals because terminal links are designed only to model the time delay caused by passage through a terminal. Their lengths and speeds are not true measures of the physical system. Only their travel times are relevant.

The high volumes highlighted by the evaluation of goal variable CONGEST occur on a rail access link in the New York City area. Access

links carry travelers between the terminal and their point of origin or ultimate destination. The congestion noted in this case may be indicative of congestion in the real system. However, the possibility exists that the congestion is caused by poor modeling of the rail system in the New York area.

4.9 Definition of New Sets

The comparisons performed thus far have indicated that the valuations of goal variables are related to the time stage in which the consequences were predicted. It makes sense, therefore, to define three new sets of consequences. Each set will include the consequences corresponding to the alternative actions in each stage of the analysis. The new sets are named STAGE1, STAGE2, and STAGE3. They correspond to 1970, 1975, and 1980, respectively.

4.10 Comparison of Goal Variables REVENUE and AVE-D-AC by Stage

A new comparison of goal variables REVENUE and AVE-D-AC is performed next in which the consequence sets STAGE1, STAGE2, and STAGE3 are used. Comparison over these sets eliminates the effect of time from the results.

The comparison for consequence set STAGE1 (1970) reveals that strategy BIG3 generates 60% less revenue for the VTOL mode than either of the other two strategies. The comparison for the other three modes indicates that their gross revenues are rather insensitive to the choice of a VTOL strategy. The largest percent difference in revenues for the other modes is 3.26% for the rail mode. The best VTOL strategy

in this stage in terms of gross VTOL revenue is CHAIN. However the NY-AREA strategy is inferior by less than 1%.

Strategy BIG3 is also inferior in terms of average district accessibility in stage 1. Strategies CHAIN and NY-AREA are better by 16.9% and 14.1%, respectively.

The results of comparisons over consequence set STAGE2 indicate that strategy BIG3 generates 10% less gross VTOL revenue than either of the other two alternative strategies. The other modes are again insensitive to the VTOL alternatives. The maximum percent difference in gross revenues for other modes is only 1.75%.

The comparison of average district accessibility reveals that strategy BIG3 has improved to within 5.25% of the best strategy, NY-AREA. Strategy CHAIN is only 0.28% worse than strategy NY-AREA.

Comparison of revenues for consequence set STAGE3 reveals that the VTOL mode now behaves in a manner very similar to that of the other three modes. Strategy NY-AREA generates gross revenues which are 1-1/2% to 2-1/2% greater than revenues for strategy BIG3 for each mode, including VTOL. The CHAIN strategy generates gross revenues which are about 1% greater than corresponding revenues for strategy BIG3, again for all modes. The similarity in the relative performance of alternative strategies for all modes in stage 3 must reflect the fact that a complete VTOL service has finally been established. Relative fares and travel times over different VTOL [illegible]es vary in a manner similar to the fares and travel times for other modes, though the absolute values are not the same.

Average accessibilities in stage 3 are almost identical for all strategies. The best strategy, BIG3, exceeds the worst strategy, NY-AREA, by only 0.31%. This fact does not indicate that the accessibilities of individual districts are necessarily the same for each strategy, however.

4.11 Further Definition of Goal Variables

The results of evaluation and comparison of the goal variables defined thus far should now be used to suggest areas for further evaluation. While goal variables BTLENECK and CONGEST revealed the maximum flows or congestion points in the transportation system, perhaps a measure of total system usage would be more indicative of the relative performance of the alternative transportation systems. In particular, we can measure the total passenger-miles and total passenger-minutes generated by each strategy in each stage by defining two new goal variables as follows:

'PASSMILE' = PRODUCT OF LINK PASSENGER VOLUME AND LENGTH
'PASSMIN' = PRODUCT OF INTERDISTRICT TRIPS AND TRAVEL TIME

Further information on the performance of each alternative can be obtained by an examination of the average fare and average interdistrict travel time, in each case weighted by the number of trips over each route. We define goal variables AVEFARE and AVETIME for this reason.

'AVEFARE' = AVERAGE OF INTERDISTRICT FARE WEIGHTED BY TRIPS

'AVETIME' = AVERAGE OF INTERDISTRICT TRAVEL TIME WEIGHTED BY TRIPS

The gross revenues examined earlier revealed that users were spending more money on VTOL than on any other mode. These figures do not represent the total cost of travel to the user, however, because the travel times of the different modes vary substantially over a given route. A goal variable could be defined which measures more closely the total cost of travel to the user by including the travel time and frequency of service as cost elements. The simplest analytical form is a linear scoring function consisting of the sum of fare, frequency, and travel time, each weighted by an appropriate utility. A constant might also be included in the scoring function to provide a non-zero cost for zero values of the variables in the function. Let us hypothesize a linear scoring function to estimate total user cost of the following form:

$$USERCOST = (U_1*TRAVEL\ TIME) + (U_2*FARE) + (U_3*K) - (U_4*FREQUENCY)$$

where U_1, U_2, U_3, U_4 are assumed utilities

and K is a frequency at which the cost due to frequency of service is assumed to be zero. Values of frequency less than K result in a positive cost, while values greater than K result in a negative cost.

We can define a goal variable of this form in DODOTRANS as follows:

'USERCOST' = SUM OF INTERDISTRICT DATA

K

TRAVEL TIME

FARE

FREQUENCY

END LIST

The value of K will be arbitrarily set to 10 for subsequent evaluations of USERCOST.

4.12 Definition of New Utilities for Goal Variable USERCOST

Goal Variable USERCOST cannot be evaluated until a four-dimensional utility has been defined. Four new utilities will be defined, each of which assumes a different value for travel time. Frequency will be valued at $.01/unit, where the units are in departures per day. Time will be assigned values of $1.20, $2.40, $4.80, and $9.60 per hour by weighting travel times in minutes to fares in dollars in ratios of .02, .04, .08, and .16, respectively. The new utilities are defined as follows:

UTILITY 'USER-1', 4 VALUES, 1.0, 1.0, 0.02, -0.01

UTILITY 'USER-2', 4 VALUES, 1.0, 1.0, 0.04, -0.01

UTILITY 'USER-3', 4 VALUES, 1.0, 1.0, 0.08, -0.01

UTILITY 'USER-4', 4 VALUES, 1.0, 1.0, 0.16, -0.01

4.13 Evaluation of New Goal Variables

The new goal variables must be evaluated for each of the VTOL strategies. Goal variable USERCOST will be evaluated four times for each set of consequences, once for each new utility. The evaluation for consequence BIG3-1 is shown. The procedure is identical for all other consequence sets.

Goal variable PASSMIN is evaluated for all routes and modes. PASSMILE is evaluated for all links. AVETIME, AVEFARE, and USERCOST are evaluated once for each mode over all routes.

4.14 Comparison of New Goal Variables

We begin the comparison by examining the total passenger-minutes for all VTOL strategies in all stages. The values increase with time for all strategies, with strategy BIG3 having the lowest value in each stage. The alternatives were ranked in ascending order on the arbitrary assumption that lower values of total system usage were preferred. The ranking of a measure of total system usage may vary for different actors. Users may prefer low usage while operators prefer high usage. The values in a given stage are within 3% of each other for all stages. An average growth in passenger-minutes of approximately 35% is experienced by all three strategies between 1970 and 1980.

A comparison of passenger-miles over consequence set VTOL-SET appears to be quite similar to the comparison of passenger-minutes. Strategy BIG3 again has the lowest value in each stage. The performance of strategy BIG3 for goal variables PASSMILE and PASSMIN can be

explained by its relative inability to generate a large VTOL demand in the earlier stages. Lower demand naturally results in lower system usage.

Goal variables AVEFARE and AVETIME are compared next over all strategies in a given stage. Since AVEFARE reflects the relative travel over different routes for a particular mode, it is not surprising to note that strategy BIG3 has a 42% higher average VTOL fare than the best strategy, CHAIN. Elimination of VTOL service to Philadelphia and Hartford reduces the number of short trips which can be taken by VTOL. The average travel time by VTOL behaves in a similar fashion for strategy BIG3 in stage 1. The average time is 20% higher for BIG3 than for the best strategy (CHAIN). In stage 2 strategy BIG3 improves the VTOL mode so that it is within 6% of strategy CHAIN. In stage 3 the three strategies exhibit average travel times and fares that are virtually equal. Average times and fares for all other modes reveal a marked insensitivity to the alternative VTOL strategies in all stages. All comparisons except one reveal differences of less than 1% in average fares and travel times for the other modes.

4.15 Definition of a Set of Utilities

Next we define a set which includes the new utilities USER-1, USER-2, USER-3, and USER-4 so that a comparison of goal variable USERCOST can be performed over a range of utilities. The set is named UTILSET1. The comparison over this set corresponds to a parametric analysis of the assumed value of travel time.

4.16 Comparison of Goal Variable USERCOST

USERCOST is compared over the range of utilities in utility set UTILSET1 for each strategy in stage 3. Values are ranked in ascending order. The values of USERCOST for a given mode were found to rank in the same order as the values assigned to travel time in the utility functions. This result is totally predictable because all other elements of USERCOST remain constant. A more interesting result is the ranking of modes for a given value of travel time. For each strategy in stage 3, the ranking of modes according to USERCOST evaluated with utility function USER-1 (with travel time valued at $1.20/hour) is the following:

1 - Road

2 - VTOL

3 - Rail

4 - Air

However, the ranking of USERCOST evaluated with the other three utility functions is noted below:

1 - VTOL

2 - Air

3 - Rail

4 - Road

Furthermore, the ranking is more pronounced, i.e. the intervals between the values for different modes become greater, as the value assigned to travel time increases. The implication to be drawn from this result is that, according to this simple model of user cost, there are critical values of travel time between $1.20/hour and $2.40/hour. The total

cost to road users throughout the system equals the total cost for users of the other modes at these critical values. This conclusion is based on the fact that the road mode, with lower fares and higher travel times, is ranked first in terms of USERCOST when time is valued at $1.20 per hour. But when travel time is assigned a value of $2.40 per hour, the road mode is ranked last. Additional utilities could be defined which assigned values to travel time between $1.20 per hour and $2.40 per hour. Parametric analysis using the COMPARE GOAL FABRIC command would define more accurately those values of travel time at which USERCOST for users of the road mode equals the costs to users of air, VTOL, and rail over all routes.

4.17 Conclusions

We have seen how the goal fabric definition, evaluation, and comparison capabilities in DODOTRANS can be used to analyze the consequences of a number of alternative transportation systems. The iterative manner in which the analyst can define an initial statement of goals, evaluate consequences in terms of those goals, compare the evaluations, form new goal statements based upon the evaluations, and repeat the process, has been illustrated.

Conclusions relevant to the problem being analyzed as well as to the methodology can be drawn from the analysis described in this chapter. These conclusions are summarized below:

1. The extremely low speeds occurring on terminal links are not necessarily indicative of overall congestion in the

transportation system. Terminal links were designed to model a time delay caused by movement through a terminal facility. Neither their lengths nor speeds are designed to measure true properties of the physical system. Only their travel times attempt to measure real world quantities.

2. The high volumes on the rail access link for passengers disembarking at New York City seem to indicate heavy congestion in that area of the transportation system for all strategies in all stages. However, the results may be caused by poor modeling of the rail network.

3. Strategy BIG3 generates less demand for VTOL travel, especially in stage 1, because of the omission of service to Philadelphia and Hartford in 1970.

4. The differences in revenues, travel times and average fares are most noticeable in earlier stages. The differences are almost indistinguishable in 1980 when VTOL service is available on all routes.

5. The conventional air, rail, and road modes are almost totally insensitive to the alternative VTOL strategies. The values of most goal variables varied less than 1% for the three alternative actions in a given stage for these modes.

6. No strategy consistently dominated the rankings of goal variables in any of the comparisons. However, strategies CHAIN and NY-AREA in general performed better than strategy BIG3.

7. All goal variables, representing both costs and benefits, tend to increase in value with time. This fact reflects the positive growth in population which occurs in the system between 1960 and 1980. The demand for transportation increases as the number of people in the region grows.
8. Parametric analysis of the value of travel time reveals that there exist values of time between $1.20 per hour and $2.40 per hour at which the road mode generates costs to users over all routes which are identical to costs incurred by users of the other modes. The road mode is less costly than all other modes when travel time is valued at $1.20 per hour.
9. Since VTOL is more competitive with conventional air travel over short routes because of its advantage in lower travel times for portions of a trip other than the line haul segment, a fourth VTOL strategy might be generated and evaluated in which the longest VTOL routes were implemented in the later stages. No districts should be excluded from VTOL service in any stage, however. Figure 4.1 illustrates a new strategy which might be considered based on the performance of the original three strategies.

4.18 Choice of a VTOL Strategy

The evaluation and comparison capabilities in DODOTRANS do not make a final selection of a best alternative for implementation in the real world. The decision-maker(s) must examine the results of the

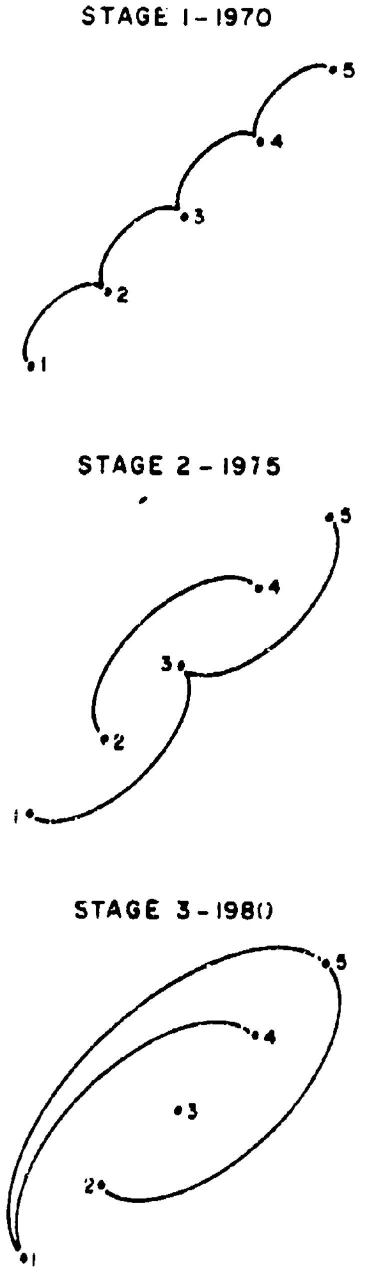

FIGURE 4.1: Proposed New VTOL Strategy

evaluations in view of the preferences of each of the relevant actors. They must decide how to weigh the preferences of the different actors before establishing a final preference ordering over all alternative actions. Finally, the decision-maker(s) must examine the preferred action and decide whether to implement it or to request that new alternatives be generated and evaluated. The final decision must always rest with the decision-maker, not the computer system.

```
DODOTRANS
SET SYSTEM REDEFINITION.
RESTORE OPERATION 'VTOL'
********************************************************************************
******  OPERATION VTOL      HAS BEEN RETRIEVED FROM DISK.
********************************************************************************

GOAL FABRIC 'VTOL-VAL'
  'BTLENECK' = MINIMUM LINK SPEED
  'CONGEST' = MAXIMUM LINK PASSENGER VOLUME
  'REVENUE' = PRODUCT OF INTERDISTRICT FARES AND TRIPS
  'AVE-D-AC' = AVERAGE DISTRICT ACCESSABILITY, UNWEIGHTED
STOP DEFINITION OF GOAL FABRIC
******  END OF CURRENT DEFINITION OF GOAL FABRIC VTOL-VAL

$
EJECT
```

See Section 4.3

DODOTRANS Listing of Chapter 4 Example

```
UTILITY 'I-1', 1 VALUE, 1.0
 ******  UTILITY VECTOR I-1       HAS BEEN DEFINED WITH  1 VALUES

UTILITY 'I-2', 2 VALUES, 1.0  1.0
 ******  UTILITY VECTOR I-2       HAS BEEN DEFINED WITH  2 VALUES
```

See Section 4.4

```
EVALUATE GOAL FABRIC 'YTCL-VAL', CONSEQUENCES 'RIG3-1'
  UTILITY 'I-1'
    'BTLENECK' FOR LINKS ALL
 ******  GOAL VARIABLE BTLENECK HAS BEEN EVALUATED WITH UTILITY I-1

    'CONGEST' FOR LINKS ALL
 ******  GOAL VARIABLE CONGEST  HAS BEEN EVALUATED WITH UTILITY I-1

  UTILITY 'I-2'
    'AVE-D-AC' FOR ALL DISTRICTS
 ******  GOAL VARIABLE AVE-D-AC HAS BEEN EVALUATED WITH UTILITY I-2

   'REVENUE' FOR ORIGINS ALL DEST ALL MODES EACH
 ******  GOAL VARIABLE REVENUE  HAS BEEN EVALUATED WITH UTILITY I-2

STOP EVALUATION
 ******  END OF CURRENT EVALUATION.

EJECT
```

See Section 4.5

```
CREATE SET 'VTOL-SET'
MEMBERS 'REC3-1' 'REC3-2' 'REC3-3' 'CHAIN-1' 'CHAIN-2' 'CHAIN-3'
MEMBERS 'NY-AREA1' 'NY-AREA2' 'NY-AREA3'
STOP
 ******  END OF CURRENT DEFINITION OF SET VTOL-SET

EJECT
```

See Section 4.6

COMPARE GOAL FABRIC 'VTOL-VAL'

BASE CONSEQUENCE 'BIG3-1'

BASE UTILITY 'I-1'

CONSEQUENCE SET 'VTOL-SET'

RANK IN DESCENDING ORDER

'BTLENECK' FOR LINKS ALL

See Section 4.7

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION	VTOL-1-1
BASE PARAMETER	NORMAL
BASE CONSEQUENCE	BIG3-1
BASE UTILITY	I-1

COMPARISON FOR CONSEQUENCE SET VTOL-SET

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** BTLENECK ******							
FOR ALL LINKS							
	BIG3-1	2.01	3	0.0	0.0	0.55	-0.01
	BIG3-2	2.00	5	-0.01	-0.67	0.54	-0.03
	BIG3-3	1.52	8	-0.49	-32.49	0.06	-0.51
	CHAIN-1	2.03	1	0.01	0.67	0.57	0.0
	CHAIN-2	2.00	4	-0.01	-0.67	0.54	-0.03
	CHAIN-3	1.46	9	-0.55	-38.05	0.0	-0.57
	NY-AREA1	2.03	2	0.01	0.67	0.57	0.0
	NY-AREA2	2.00	6	-0.01	-0.67	0.54	-0.03
	NY-AREA3	1.53	7	-0.48	-31.45	0.07	-0.5[illegible]

RANK IN ASCENDING ORDER

'CONGEST' FOR LINKS ALL

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION VTOL-1-1
BASE PARAMETER NORMAL
BASE CONSEQUENCE BIG3-1
BASE UTILITY 1-1

COMPARISON FOR CONSEQUENCE SET VTOL-SET

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** CONGEST ******							
FOR ALL LINKS	BIG3-1	33644.00	3	0.0	0.0	1140.00	-7546.00
	BIG3-2	35631.00	4	1987.00	5.58	3127.00	-5559.00
	BIG3-3	40996.00	7	7352.00	17.93	8492.00	-194.00
	CHAIN-1	32504.00	2	-1140.00	-3.51	0.0	-8686.00
	CHAIN-2	35999.00	6	2355.00	6.54	3495.00	-5191.00
	CHAIN-3	41107.00	8	7463.00	18.16	8603.00	-83.00
	NY-AREA1	32504.00	1	-1140.00	-3.51	0.0	-8686.00
	NY-AREA2	35565.00	5	2125.00	6.46	3465.00	-5221.00
	NY-AREA3	41190.00	9	7546.00	18.32	8686.00	0.0

BASE UTILITY 'I-2'

RANK IN DESCENDING ORDER

'AVE-C-AC' FOR ALL DISTRICTS

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION	VTOL-1-1
BASE PARAMETER	NORMAL
BASE CONSEQUENCE	BIG3-1
BASE UTILITY	I-2

COMPARISON FOR CONSEQUENCE SET VTOL-SET

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** AVE-C-AC ******							
FOR ALL DISTRICTS	BIG3-1	23033.15	9	0.0	0.0	0.0	-8882.54
	BIG3-2	28191.64	6	5158.49	18.30	5158.49	-3724.05
	BIG3-3	31915.69	1	8882.54	27.83	8882.54	0.0
	CHAIN-1	27705.92	7	4672.77	16.87	4672.77	-4209.77
	CHAIN-2	29670.35	5	6637.20	22.37	6637.20	-2245.34
	CHAIN-3	31883.59	2	8850.44	27.76	8850.44	-32.10
	NY-AREA1	26828.22	8	3795.07	14.15	3795.07	-5087.46
	NY-AREA2	29756.02	4	6722.87	22.59	6722.87	-2159.66
	NY-AREA3	31816.00	3	8782.85	27.61	8782.85	-99.69

'REVENUE' FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION VTOL-1-1
BASE PARAMETER NORMAL
BASE CONSEQUENCE BIG3-1
BASE UTILITY I-2

COMPARISON FOR CONSEQUENCE SET VTOL-SET

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** REVENUE ******							
ORIGIN ALL DEST ALL MODE VTOL	BIG3-1	202443.87	9	0.0	0.0	0.0	-634243.25
	BIG3-2	610148.31	6	407704.44	66.82	407704.44	-226538.81
	BIG3-3	816117.12	3	613673.25	75.19	613673.25	-20570.00
	CHAIN-1	524317.00	7	321873.12	61.39	321873.12	-312370.12
	CHAIN-2	673674.75	5	471230.87	69.95	471230.87	-163012.37
	CHAIN-3	824323.56	2	621880.06	75.44	621880.06	-12363.19
	NY-AREA1	512190.44	8	309746.56	60.47	309746.56	-324496.69
	NY-AREA2	680405.37	4	477961.50	70.25	477961.50	-156281.75
	NY-AREA3	836687.12	1	634243.25	75.80	634243.25	0.0
ORIGIN ALL DEST ALL MODE AIR	BIG3-1	166880.00	7	0.0	0.0	3077.37	-56375.31
	BIG3-2	189015.00	5	22135.00	11.71	25212.37	-34240.31
	BIG3-3	218178.87	3	51298.87	23.51	54376.25	-5076.44
	CHAIN-1	163802.62	8	-3077.37	-1.88	0.0	-59452.69

	CHAIN-2	189295.06	4	22415.06	11.84	25492.44	-33960.25
	CHAIN-3	220225.37	2	53345.37	24.22	56422.75	-3029.94
	NY-AREA1	163802.62	5	-3077.37	-1.88	0.0	-59452.69
	NY-AREA2	188734.50	6	21854.50	11.58	24931.87	-34520.81
	NY-AREA3	223255.31	1	56375.31	25.25	59452.69	0.0
ORIGIN ALL DEST ALL MODE RAIL	RIG3-1	129289.81	7	0.0	0.0	4086.44	-43334.44
	RIG3-2	143585.12	6	14295.31	9.96	18385.75	-29035.12
	RIG3-3	168658.69	3	39368.87	23.36	43455.31	-3965.56
	CHAIN-1	125203.37	8	-4086.44	-3.26	0.0	-47420.87
	CHAIN-2	146149.56	4	16859.75	11.54	20946.19	-26474.69
	CHAIN-3	170196.37	2	40906.56	24.03	44993.00	-2427.87
	NY-AREA1	125203.37	8	-4086.44	-3.26	0.0	-47420.87
	NY-AREA2	145593.35	5	16303.54	11.20	20390.37	-27030.50
	NY-AREA3	172624.25	1	43334.44	25.10	47420.87	0.0
ORIGIN ALL DEST ALL MODE ROAD	RIG3-1	332308.37	7	0.0	0.0	6963.69	-66009.56
	RIG3-2	352997.50	6	20689.12	5.86	27652.81	-45320.44
	RIG3-3	392730.25	3	60421.87	15.39	67385.56	-5587.69
	CHAIN-1	325344.69	8	-6963.69	-2.14	0.0	-72973.25
	CHAIN-2	355065.31	4	22756.94	6.41	29720.62	-43252.62
	CHAIN-3	395417.37	2	63109.00	15.96	70072.69	-2900.56
	NY-AREA1	325344.69	8	-6963.69	-2.14	0.0	-72973.25
	NY-AREA2	353951.62	5	21643.25	6.11	28606.94	-44366.31
	NY-AREA3	358317.94	1	26009.56	16.57	72973.25	0.0

STEP COMPARISON

****** END OF GOAL FABRIC COMPARISON

See Section 4.8

```
WRITE EVALUATION RESULTS FOR GOAL FABRIC 'VTOL-VAL' -
  VARIABLE 'BTLENECK', UTILITIES ALL, CONSEQUENCES ALL
```

GOAL VARIABLE NAME	UTILITY FUNCTION NAME	CONSEQUENCE FILE NAME	VALUE	RANGE SPECIFICATION
BTLENECK	1-1	NOVTOL67 ******	2.05 VALUE FOUND FOR LINK	FOR ALL LINKS 1101 TO 1301 ******
BTLENECK	1-1	NOVTOL65 ******	2.04 VALUE FOUND FOR LINK	FOR ALL LINKS 1101 TO 1301 ******
BTLENECK	1-1	BIG3-1 ******	2.01 VALUE FOUND FOR LINK	FOR ALL LINKS 1101 TO 1301 ******
BTLENECK	1-1	BIG3-2 ******	2.00 VALUE FOUND FOR LINK	FOR ALL LINKS 1101 TO 1301 ******
BTLENECK	1-1	BIG3-3 ******	1.52 VALUE FOUND FOR LINK	FOR ALL LINKS 3302 TO 3102 ******
BTLENECK	1-1	CHAIN-1 ******	2.02 VALUE FOUND FOR LINK	FOR ALL LINKS 1101 TO 1301 ******
BTLENECK	1-1	CHAIN-2 ******	2.00 VALUE FOUND FOR LINK	FOR ALL LINKS 1101 TO 1301 ******
BTLENECK	1-1	CHAIN-3 ******	1.46 VALUE FOUND FOR LINK	FOR ALL LINKS 3302 TO 3102 ******
BTLENECK	1-1	NY-AREA1 ******	2.03 VALUE FOUND FOR LINK	FOR ALL LINKS 1101 TO 1301 ******
BTLENECK	1-1	NY-AREA2 ******	2.00 VALUE FOUND FOR LINK	FOR ALL LINKS 1101 TO 1301 ******
BTLENECK	1-1	NY-AREA3 ******	1.53 VALUE FOUND FOR LINK	FOR ALL LINKS 3302 TO 3102 ******

EJECT

WRITE EVALUATION RESULTS FOR GOAL CHOICE (VTCL-VAL) -
VARIABLE (CONGEST), UTILITIES ALL, CONSEQUENCES ALL

GOAL VARIABLE NAME	UTILITY FUNCTION NAME	CONSEQUENCE FILE NAME	VALUE	RANGE SPECIFICATION
CONGEST	1-1	NOVTPLA2 ******	30180.00 VALUE FOUND FOR LINK	FOR ALL LINKS 3103 TO 3303 ******
CONGEST	1-1	NOVTPLAS ******	31533.00 VALUE FOUND FOR LINK	FOR ALL LINKS 3103 TO 3303 ******
CONGEST	1-1	9103-1 ******	33666.00 VALUE FOUND FOR LINK	FOR ALL LINKS 3103 TO 3303 ******
CONGEST	1-1	9103-2 ******	35831.00 VALUE FOUND FOR LINK	FOR ALL LINKS 3103 TO 3303 ******
CONGEST	1-1	9103-3 ******	40886.00 VALUE FOUND FOR LINK	FOR ALL LINKS 3103 TO 3303 ******
CONGEST	1-1	CHAIN-1 ******	37576.00 VALUE FOUND FOR LINK	FOR ALL LINKS 3103 TO 3303 ******
CONGEST	1-1	CHAIN-2 ******	36000.00 VALUE FOUND FOR LINK	FOR ALL LINKS 3103 TO 3303 ******
CONGEST	1-1	CHAIN-3 ******	41137.00 VALUE FOUND FOR LINK	FOR ALL LINKS 3103 TO 3303 ******
CONGEST	1-1	AV-AREA1 ******	32576.00 VALUE FOUND FOR LINK	FOR ALL LINKS 3103 TO 3303 ******
CONGEST	1-1	AV-AREA2 ******	36540.00 VALUE FOUND FOR LINK	FOR ALL LINKS 3103 TO 3303 ******
CONGEST	1-1	AV-AREA3 ******	41157.00 VALUE FOUND FOR LINK	FOR ALL LINKS 3103 TO 3303 ******

EJECT

```
$
CREATE SET 'STAGE1'
  MEMBERS 'BIG3-1'  'CHAIN-1'  'NY-AREA1'
STOP DEFINITION
 ******  END OF CURRENT DEFINITION OF SET STAGE1

$
CREATE SET 'STAGE2'
  MEMBERS 'BIG3-2'  'CHAIN-2'  'NY-AREA2'
STOP DEFINITION
 ******  END OF CURRENT DEFINITION OF SET STAGE2

$
CREATE SET 'STAGE3'
  MEMBERS  'BIG3-3'  'CHAIN-3'  'NY-AREA3'
STOP DEFINITION
 ******  END OF CURRENT DEFINITION OF SET STAGE3

EJECT
```

See Section 4.9

```
COMPARE [illegible] FABRIC "[illegible]"

BASE CONSEQUENCE "[illegible]"
BASE UTILITY "[illegible]"
CONSEQUENCE SET "STAGE1"
RANK IN DESCENDING ORDER
  "REVENUE" FOR ORIGINS ALL DEST ALL MODES EACH
```

See Section 4.10

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION VTOL-1-1
BASE PARAMETER NORMAL
BASE CONSEQUENCE BIG3-1
BASE UTILITY 1-2

COMPARISON FOR CONSEQUENCE SET STAGE1

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** REVENUE ******							
ORIGIN ALL DEST ALL MODE VTOL	BIG3-1	202443.87	3	0.0	0.0	0.0	-321873.12
	CHAIN-1	524317.00	1	321873.12	61.35	321873.12	0.0
	NY-AREA1	512190.44	2	309746.56	60.47	309746.56	-12126.56
ORIGIN ALL DEST ALL MODE AIR	BIG3-1	166880.00	1	0.0	0.0	3077.37	0.0
	CHAIN-1	163902.62	2	-3077.37	-1.88	0.0	-3077.37
	NY-AREA1	163902.62	3	-3077.37	-1.84	0.0	-3077.37
ORIGIN ALL DEST ALL MODE RAIL	BIG3-1	129289.81	1	0.0	0.0	4086.44	0.0
	CHAIN-1	125203.37	2	-4086.44	-3.26	0.0	-4086.44
	NY-AREA1	125203.37	3	-4086.44	-3.26	0.0	-4086.44
ORIGIN ALL DEST ALL MODE ROAD	BIG3-1	332328.37	1	0.0	0.0	6963.69	0.0
	CHAIN-1	325364.69	2	-6963.65	-2.14	0.0	-6963.69
	NY-AREA1	325364.69	3	-6963.65	-2.14	0.0	-6963.69

'AVE-C-AC' FOR ALL DISTRICTS

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION	VTOL-1-1
BASE PARAMETER	NORMAL
BASE CONSEQUENCE	BIG3-1
BASE UTILITY	1-2

COMPARISON FOR CONSEQUENCE SET STAGE1

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** AVE-C-AC ******							
FOR ALL DISTRICTS	BIG3-1	23033.15	3	0.0	0.0	0.0	-4672.77
	CHAIN-1	27705.92	1	4672.77	16.87	4672.77	0.0
	NY-AREA1	26828.22	2	3795.07	14.15	3795.07	-877.70

BASE CONSEQUENCE 'BIG3-2'

CONSEQUENCE SET 'STAGE2'

RANK IN DESCENDING ORDER

'REVENUE' FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION	VTOL-1-2
BASE PARAMETER	NORMAL
BASE CONSEQUENCE	BIG3-2
BASE UTILITY	1-2

COMPARISON FOR CONSEQUENCE SET STAGE2

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** REVENUE ******							
ORIGIN ALL DEST ALL MODE VTOL	BIG3-2	610148.31	3	0.0	0.0	0.0	-70257.06
	CHAIN-2	673674.75	2	63526.44	5.43	63526.44	-6730.62
	NY-AREA2	680405.37	1	70257.06	10.33	70257.06	0.0
ORIGIN ALL DEST ALL MODE AIR	BIG3-2	189015.02	2	0.0	0.0	280.50	-280.06
	CHAIN-2	189295.56	1	280.56	0.15	560.56	0.0
	NY-AREA2	188734.50	3	-280.50	-0.15	0.0	-560.56
ORIGIN ALL DEST ALL MODE RAIL	BIG3-2	143589.12	3	0.0	0.0	0.0	-2560.44
	CHAIN-2	146149.56	1	2560.44	1.75	2560.44	0.0
	NY-AREA2	145593.75	2	2004.62	1.38	2004.62	-555.81

ORIGIN ALL
DEST ALL
PCDE FCAC

BIG3-2	352997.50	3	0.0	0.0	0.0	-2067.81
CHAIN-2	355065.31	1	2067.81	0.58	2067.81	0.0
NY-AREA2	353551.62	2	954.13	0.27	954.13	-1113.69

'AVE-C-AC' FOR ALL DISTRICTS

******** COMPARISON OF GOAL FABRIC VTCL-VAL ********

BASE ACTION VTCL-1-2
BASE PARAMETER NORMAL
BASE CONSEQUENCE RIG3-2
BASE UTILITY 1-2

COMPARISON FOR CONSEQUENCE SET STAGE2

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** AVE-C-AC ******							
FOR ALL DISTRICTS	RIG3-2	28191.64	3	0.0	0.0	0.0	-1564.39
	CHAIN-2	29670.35	2	1478.71	4.98	1478.71	-85.68
	NY-AREA2	29756.03	1	1564.39	5.26	1564.39	0.0

BASE CONSEQUENCE *BIG3-3*

CONSEQUENCE SET *STAGE3*

REVENUE FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION VTOL-1-3
BASE PARAMETER NORMAL
BASE CONSEQUENCE BIG3-3
BASE UTILITY 1-2

COMPARISON FOR CONSEQUENCE SET STAGE3

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** REVENUE ******							
ORIGIN ALL DEST ALL MODE VTOL	BIG3-3	816117.12	3	0.0	0.0	0.0	-20570.00
	CHAIN-3	824323.94	2	8206.81	1.00	8206.91	-12363.18
	NY-AREA3	836687.12	1	20570.00	2.46	20570.00	0.0
ORIGIN ALL DEST ALL MODE AIR	BIG3-3	218178.87	3	0.0	0.0	0.0	-5076.44
	CHAIN-3	220225.37	2	2046.50	0.93	2046.50	-3029.94
	NY-AREA3	223255.31	1	5076.44	2.27	5076.44	0.0
ORIGIN ALL DEST ALL MODE RAIL	BIG3-3	168658.69	3	0.0	0.0	0.0	-3965.56
	CHAIN-3	170196.37	2	1537.69	0.91	1537.69	-2427.87
	NY-AREA3	172624.25	1	3965.56	2.35	3965.56	0.0

ORIGIN ALL
DEST ALL
MODE ROAD

RIG3-3	392733.25	3	0.0	0.0	0.0	-5587.69
CHAIN-3	395417.37	2	2687.12	0.68	2687.12	-2900.56
NY-AREA3	398317.94	1	5587.69	1.40	5587.69	0.0

'AVE-C-AC' FOR ALL DISTRICTS

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION	VTOL-1-3
BASE PARAMETER	NORMAL
BASE CONSEQUENCE	BIG3-3
BASE UTILITY	1-2

COMPARISON FOR CONSEQUENCE SET STAGE3

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** AVE-C-AC ******							
FOR ALL DISTRICTS							
	BIG3-3	31915.69	1	0.0	0.0	99.69	0.0
	CHAIN-3	31883.59	2	-32.10	-0.10	67.59	-32.10
	NY-AREA3	31816.00	3	-99.69	-0.31	0.0	-99.69

STOP COMPARISON

****** END OF GOAL FABRIC COMPARISON

```
GOAL FABRIC *VTOL-VAL*
  *PASSMILE* = PRODUCT OF LINK PASSENGER VOLUME AND LENGTH
  *PASSMIN* = PRODUCT OF INTERDISTRICT TRIPS AND TRAVEL TIME
  *USERCOST* = SUM OF INTERDISTRICT DATA,
    10.0
    FARE
    TRAVEL TIME
    FREQUENCY
  END LIST
  *AVEFARE* = AVERAGE OF INTERDISTRICT FARE WEIGHTED BY TRIPS
  *AVETIME* = AVERAGE OF INTERDISTRICT TRAVEL TIME WEIGHTED BY TRIPS
STOP DEFINITION
 ******  END OF CURRENT DEFINITION OF GOAL FABRIC VTOL-VAL

EJECT
```

See Section 4.11

```
UTILITY *USER-1*, 4 VALUES, 1.0  1.0  0.02  -0.01
 ******  UTILITY VECTOR USER-1   HAS BEEN DEFINED WITH  4 VALUES

UTILITY *USER-2*, 4 VALUES, 1.0  1.0  0.04  -0.01
 ******  UTILITY VECTOR USER-2   HAS BEEN DEFINED WITH  4 VALUES

UTILITY *USER-3*, 4 VALUES, 1.0  1.0  0.08  -0.01
 ******  UTILITY VECTOR USER-3   HAS BEEN DEFINED WITH  4 VALUES

UTILITY *USER-4*, 4 VALUES, 1.0  1.0  0.15  -0.01
 ******  UTILITY VECTOR USER-4   HAS BEEN DEFINED WITH  4 VALUES

$
EJECT
```

See Section 4.12

```
EVALUATE GOAL FABRIC 'VTCL-VAL', CONSEQUENCES 'BIG3-1'
 UTILITY 'I-2'
   'AVEFARE' FOR ORIGINS ALL DEST ALL MODES EACH
****** GOAL VARIABLE AVEFARE  HAS BEEN EVALUATED WITH UTILITY I-2

   'AVETIME' FOR ORIGINS ALL DEST ALL MODES EACH
****** GOAL VARIABLE AVETIME  HAS BEEN EVALUATED WITH UTILITY I-2

   'PASSMIN' FOR ORIGINS ALL DEST ALL MODES ALL
****** GOAL VARIABLE PASSMIN  HAS BEEN EVALUATED WITH UTILITY I-2

   'PASSMILE' FOR LINKS ALL
****** GOAL VARIABLE PASSMILE HAS BEEN EVALUATED WITH UTILITY I-2

 UTILITY 'USER-1'
   'USERCOST' FOR ORIGINS ALL DEST ALL MODES EACH
****** GOAL VARIABLE USERCOST HAS BEEN EVALUATED WITH UTILITY USER-1

 UTILITY 'USER-2'
   'USERCOST' FOR ORIGINS ALL DEST ALL MODES EACH
****** GOAL VARIABLE USERCOST HAS BEEN EVALUATED WITH UTILITY USER-2

 UTILITY 'USER-3'
   'USERCOST' FOR ORIGINS ALL DEST ALL MODES EACH
****** GOAL VARIABLE USERCOST HAS BEEN EVALUATED WITH UTILITY USER-3

 UTILITY 'USER-4'
   'USERCOST' FOR ORIGINS ALL DEST ALL MODES EACH
****** GOAL VARIABLE USERCOST HAS BEEN EVALUATED WITH UTILITY USER-4

STOP EVALUATION
****** END OF CURRENT EVALUATION.

EJECT
```

See Section 4.13

COMPARE GOAL FABRIC 'VTOL-VAL'

See Section 4.14

BASE CONSEQUENCE 'BIG3-1'

BASE UTILITY 'I-2'

CONSEQUENCE SET 'VTOL-SET'

RANK IN ASCENDING ORDER

'PASSMIN' FOR ORIGINS ALL DEST ALL MODES ALL

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION VTOL-1-1
BASE PARAMETER NORMAL
BASE CONSEQUENCE BIG3-1
BASE UTILITY I-2

COMPARISON FOR CONSEQUENCE SET VTOL-SET

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** PASSMIN ******							
ORIGIN ALL DEST ALL MODE ALL	BIG3-1	36274928.00	1	0.0	0.0	0.0	-21533456.00
	BIG3-2	43656112.00	4	7381184.00	16.91	7381184.00	-14152272.00
	BIG3-3	56486544.00	7	20211616.00	35.78	20211616.00	-1321840.00
	CHAIN-1	37194256.00	3	919328.00	2.47	919328.00	-20614128.00
	CHAIN-2	44917392.00	6	8642464.00	19.24	8642464.00	-12890992.00
	CHAIN-3	56815456.00	8	20540528.00	36.15	20540528.00	-992928.00
	NY-AREA1	37024416.00	2	749488.00	2.02	749488.00	-20783968.00
	NY-AREA2	44720592.00	5	8445664.00	18.89	8445664.00	-13087792.00
	NY-AREA3	57808384.00	9	21533456.00	37.25	21533456.00	0.0

'PASSMILE' FOR LINKS ALL

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION	VTOL-1-1
BASE PARAMETER	NORMAL
BASE CONSEQUENCE	BIG3-1
BASE UTILITY	I-2

COMPARISON FOR CONSEQUENCE SET VTOL-SET

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** PASSMILE ******							
FOR ALL LINKS	BIG3-1	25390448.00	1	0.0	0.0	0.0	-15063600.00
	BIG3-2	33262624.00	4	7872176.00	23.67	7872176.00	-7191424.00
	BIG3-3	39707872.00	7	14317424.00	36.06	14317424.00	-746176.00
	CHAIN-1	29494848.00	2	4104400.00	13.92	4104400.00	-10959200.00
	CHAIN-2	34441568.00	5	9051120.00	26.28	9051120.00	-6012480.00
	CHAIN-3	40034208.00	8	14643760.00	36.58	14643760.00	-419840.00
	NY-AREA1	29509392.00	3	4118944.00	13.96	4118944.00	-10944656.00
	NY-AREA2	34516880.00	6	9126432.00	26.44	9126432.00	-5937168.00
	NY-AREA3	40454048.00	9	15063600.00	37.24	15063600.00	0.0

CONSEQUENCE SET 'STAGE1'

RANK IN ASCENDING ORDER

'AVEFARE' FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION	VTOL-I-1
BASE PARAMETER	NORMAL
BASE CONSEQUENCE	BIG3-1
BASE UTILITY	1-2

COMPARISON FOR CONSEQUENCE SET STAGE1

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** AVEFARE ******							
ORIGIN ALL DEST ALL MODE VTOL	BIG3-1	16.71	3	0.0	0.0	4.97	0.0
	CHAIN-1	11.74	1	-4.97	-42.33	0.0	-4.97
	NY-AREAI	12.39	2	-4.32	-34.85	0.56	-4.32
ORIGIN ALL DEST ALL MODE AIR	BIG3-1	16.08	1	0.0	0.0	0.0	-0.05
	CHAIN-1	16.13	3	0.05	0.28	0.05	0.0
	NY-AREAI	16.13	2	0.05	0.28	0.05	0.0
ORIGIN ALL DEST ALL MODE RAIL	BIG3-1	7.51	1	0.0	0.0	0.0	-0.03
	CHAIN-1	7.54	3	0.03	0.38	0.03	0.0
	NY-AREAI	7.54	2	0.03	0.39	0.03	0.0

ORIGIN ALL
DEST ALL
MODE ROAD

BIGH-1	3.21	1	0.0	0.0	0.0	-0.02
CHAIN-1	3.23	3	0.02	0.52	0.02	0.0
NY-AREA1	3.23	2	0.02	0.52	0.02	0.0

'AVETIME' FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION VTOL-1-1
BASE PARAMETER NORMAL
BASE CONSEQUENCE BIG3-1
BASE UTILITY 1-2

COMPARISON FOR CONSEQUENCE SET STAGE1

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** AVETIME ******							
ORIGIN ALL DEST ALL MODE VTOL	BIG3-1	103.47	3	0.0	0.0	17.51	0.0
	CHAIN-1	85.95	1	-17.51	-20.37	0.0	-17.51
	NY-AREA1	88.79	2	-14.67	-16.52	2.94	-14.67
ORIGIN ALL DEST ALL MODE AIR	BIG3-1	141.29	1	0.0	0.0	0.0	-0.10
	CHAIN-1	141.39	3	0.10	0.07	0.10	0.0
	NY-AREA1	141.39	2	0.10	0.07	0.10	0.0
ORIGIN ALL DEST ALL MODE RAIL	BIG3-1	194.83	1	0.0	0.0	0.0	-0.79
	CHAIN-1	195.67	3	0.79	0.40	0.79	0.0
	NY-AREA1	195.67	2	0.79	0.40	0.79	0.0
ORIGIN ALL DEST ALL MODE ROAD	BIG3-1	291.75	4	0.0	0.0	7.45	0.0

CHAIN-1	284.35	2	-7.40	-2.60	0.0	-7.40
NY-AREA1	284.35	1	-7.40	-2.60	0.0	-7.40

BASE CONSEQUENCE 'BIG3-2'

CONSEQUENCE SET 'STAGE2'

'AVEFARE' FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF GOAL_FABRIC VTOL-VAL ********

BASE ACTION VTOL-1-2
BASE PARAMETER NORMAL
BASE CONSEQUENCE BIG3-2
BASE UTILITY 1-2

COMPARISON FOR CONSEQUENCE SET STAGE2

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** AVEFARE ******							
ORIGIN ALL DEST ALL MODE VTOL	BIG3-2	12.45	3	0.0	0.0	0.76	0.0
	CHAIN-2	11.70	1	-0.76	-6.51	0.0	-0.76
	NY-AREA2	11.74	2	-0.72	-6.11	0.04	-0.72
ORIGIN ALL DEST ALL MODE AIR	BIG3-2	17.13	3	0.0	0.0	0.03	0.0
	CHAIN-2	16.10	2	-0.03	-0.19	0.00	-0.03
	NY-AREA2	16.09	1	-0.03	-0.21	0.0	-0.03
ORIGIN ALL DEST ALL MODE RAIL	BIG3-2	7.54	3	0.0	0.0	0.03	0.0
	CHAIN-2	7.52	2	-0.02	-0.31	0.00	-0.02
	NY-AREA2	7.51	1	-0.03	-0.34	0.0	-0.03

CRIGIN ALL
CEST ALL
MODE ROAC

BIG3-2	3.21	3	0.0	0.0	C.01	0.C
CHAIN-2	3.20	1	-0.01	-C.39	C.0	-0.C1
NY-AREA2	3.23	2	-0.31	-C.34	C.30	-0.C1

'AVETIME' FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION	VTOL-1-2
BASE PARAMETER	NORMAL
BASE CONSEQUENCE	BIG3-2
BASE UTILITY	1-2

COMPARISON FOR CONSEQUENCE SET STAGE2

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** AVETIME ******							
ORIGIN ALL DEST ALL MODE VTOL	BIG3-2	89.69	3	0.0	0.0	2.18	0.0
	CHAIN-2	87.51	1	-2.18	-2.49	0.0	-2.18
	NY-AREA2	87.89	2	-1.80	-2.05	0.38	-1.80
ORIGIN ALL DEST ALL MODE AIR	BIG3-2	141.78	3	0.0	0.0	0.17	0.0
	CHAIN-2	141.66	2	-0.12	-0.08	0.05	-0.12
	NY-AREA2	141.61	1	-0.17	-0.12	0.0	-0.17
ORIGIN ALL DEST ALL MODE RAIL	BIG3-2	196.26	3	0.0	0.0	0.85	0.0
	CHAIN-2	195.47	2	-0.79	-0.41	0.06	-0.79
	NY-AREA2	195.41	1	-0.85	-0.43	0.0	-0.85
ORIGIN ALL DEST ALL MODE ROAD	BIG3-2	308.32	1	0.0	0.0	0.0	-1.94

CHAIN-2	310.26	3	1.94	0.62	1.94	0.0
NY-AMEA2	309.3C	2	C.98	C.32	0.98	-0.96

BASE CONSEQUENCE *BIG3-3*

CONSEQUENCE SET *STAGE3*

AVEFARE FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION VTOL-1-3
BASE PARAMETER NORMAL
BASE CONSEQUENCE BIG3-3
BASE UTILITY 1-2

COMPARISON FOR CONSEQUENCE SET STAGE3

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** AVEFARE ******							
ORIGIN ALL DEST ALL MODE VTOL	BIG3-3	11.74	1	0.0	0.0	0.0	-0.01
	CHAIN-3	11.74	2	0.00	0.02	0.00	-0.01
	NY-AREA3	11.75	3	0.01	0.07	0.01	0.0
ORIGIN ALL DEST ALL MODE AIR	BIG3-3	16.08	1	0.0	0.0	0.0	-0.02
	CHAIN-3	16.09	2	0.01	0.06	0.01	-0.01
	NY-AREA3	16.10	3	0.02	0.15	0.02	0.0
ORIGIN ALL DEST ALL MODE RAIL	BIG3-3	7.50	1	0.0	0.0	0.0	-0.01
	CHAIN-3	7.51	2	0.00	0.02	0.00	-0.01
	NY-AREA3	7.51	3	0.01	0.12	0.01	0.0

CRIGIN	ALL							
CEST	ALL							
MODE	ROAC	HIGH-3	3.17	1	0.0	C.0	0.0	-0.CC
		CHAIN-3	3.14	3	0.00	0.10	0.00	C.C
		NY-AREA3	3.17	2	0.00	0.04	0.00	-0.CC

'AVETIME' FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION VTOL-1-3
BASE PARAMETER NORMAL
BASE CONSEQUENCE BIG3-3
BASE UTILITY I-2

COMPARISON FOR CONSEQUENCE SET STAGE3

GOAL VARIABLE	CONSEQUENCE	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** AVETIME ******							
ORIGIN ALL DEST ALL MODE VTOL	BIG3-3	88.63	1	0.0	0.0	0.0	-0.08
	CHAIN-3	88.66	2	0.02	0.03	0.02	-0.05
	NY-AREA3	88.71	3	0.08	0.09	0.08	0.0
ORIGIN ALL DEST ALL MODE AIR	BIG3-3	141.71	1	0.0	0.0	0.0	-0.22
	CHAIN-3	141.76	2	0.05	0.04	0.05	-0.16
	NY-AREA3	141.92	3	0.22	0.15	0.22	0.0
ORIGIN ALL DEST ALL MODE RAIL	BIG3-3	195.86	1	0.0	0.0	0.0	-0.16
	CHAIN-3	195.90	2	[illegible]	0.02	0.03	-0.12
	NY-AREA3	196.02	3	0.16	0.08	0.16	0.0
ORIGIN ALL DEST ALL MODE ROAD	BIG3-3	355.44	?	0.0	0.0	0.17	-3.26

```
          CHAIN-3          355.06     1          -0.37   -0.19        0.0       -3.63
          NY-AREA3         358.70     3           3.26    0.91        3.63       0.0

STOP COMPARISON
 ******  END OF GOAL FABRIC COMPARISON

CREATE SET  'UTILSET1'
  MEMBERS 'USER-1' 'USER-2' 'USER-3'  'USER-4'
STOP DEFINITION
 ******  END OF CURRENT DEFINITION OF SET UTILSET1
```

See Section 4.15

See Section 4.16

COMPARE COAL FABRIC 'VTCL-VAL'

UTILITY SET 'UTILSET1'

BASE UTILITY 'USER-1'

'USERCOST' FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF COAL FABRIC VTCL-VAL ********

BASE ACTION	VTCL-1-3
BASE PARAMETER	NORMAL
BASE CONSEQUENCE	BIC3-3
BASE UTILITY	USER-1

COMPARISON FOR UTILITY SET UTILSET1

GOAL VARIABLE	UTILITY	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** USERCOST ******							
ORIGIN ALL DEST ALL MODE VTCL	USER-1	543.52	1	0.0	0.0	0.0	-291.93
	USER-2	585.22	2	41.70	7.13	41.70	-250.22
	USER-3	668.63	3	125.11	18.71	125.11	-166.82
	USER-4	835.45	4	291.93	34.96	291.93	0.0
ORIGIN ALL DEST ALL MODE AIR	USER-1	620.27	1	0.0	0.0	0.0	-420.67
	USER-2	680.37	2	60.10	8.83	60.10	-360.57
	USER-3	830.56	3	183.29	22.52	180.29	-240.38
	USER-4	1040.95	4	420.67	60.41	420.67	0.0
ORIGIN ALL DEST ALL MODE RAIL	USER-1	562.56	1	0.0	0.0	0.0	-857.47
	USER-2	[illegible]	2	122.50	17.88	122.50	-734.97

	USER-3	930.05	3	367.49	39.51	367.49	-489.98
	USER-4	1420.93	4	857.47	60.38	857.47	0.0
CRIEIA ALL CEST ALL MCDE RCAD	USER-1	499.67	1	0.0	0.0	0.0	-1482.93
	USER-2	711.52	2	211.85	25.77	211.85	-1271.09
	USER-3	1135.21	3	635.54	55.58	635.54	-847.39
	USER-4	1582.60	4	1482.93	74.80	1482.93	0.0

BASE CONSEQUENCE 'CHAIN-3'

'USERCOST' FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION VTOL-2-3
BASE PARAMETER NORMAL
BASE CONSEQUENCE CHAIN-3
BASE UTILITY USER-1

COMPARISON FOR UTILITY SET UTILSET1

GOAL VARIABLE	UTILITY	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** USERCOST ******							
ORIGIN ALL DEST ALL MODE VTOL	USER-1	543.52	1	0.0	0.0	0.0	-291.93
	USER-2	585.22	2	41.70	7.13	41.70	-250.22
	USER-3	668.63	3	125.11	18.71	125.11	-166.82
	USER-4	835.45	4	291.93	34.94	291.93	0.0
ORIGIN ALL DEST ALL MODE AIR	USER-1	620.27	1	0.0	0.0	0.0	-420.67
	USER-2	680.37	2	60.10	8.83	60.10	-360.57
	USER-3	800.56	3	180.29	22.52	180.29	-240.38
	USER-4	1040.95	4	420.67	40.41	420.67	0.0
ORIGIN ALL DEST ALL MODE RAIL	USER-1	562.59	1	0.0	0.0	0.0	-857.69
	USER-2	685.12	2	122.53	17.88	122.53	-735.17
	USER-3	930.18	3	367.59	39.52	367.59	-490.11

	USFR-4	1420.29	4	857.69	60.39	857.69	0.0
CRICIN ALL DEST ALL MODE ROAD	USER-1	499.30	1	C.C	C.0	0.0	-148C.30
	USER-2	71C.77	2	211.47	29.75	211.47	-1268.83
	USER-3	1133.71	3	634.41	55.96	634.41	-845.89
	USFR-4	1979.60	4	148C.3C	74.78	1480.30	0.0

BASE CONSEQUENCE 'NY-AREA3'

'USERCOST' FOR ORIGINS ALL DEST ALL MODES EACH

******** COMPARISON OF GOAL FABRIC VTOL-VAL ********

BASE ACTION VTOL-3-1
BASE PARAMETER NORMAL
BASE CONSEQUENCE NY-AREA3
BASE UTILITY USER-1

COMPARISON FOR UTILITY SET UTILSET1

GOAL VARIABLE	UTILITY	VALUE	RANKING	DIFFERENCE - BASE ABSOLUTE	DIFFERENCE - BASE PERCENT	DIFFERENCE FROM MINIMUM	DIFFERENCE FROM MAXIMUM
****** USERCOST ******							
ORIGIN ALL DEST ALL MODE VTOL	USER-1	543.52	1	0.0	0.0	0.0	-291.93
	USER-2	585.22	2	41.70	7.13	41.70	-250.22
	USER-3	668.63	3	125.11	18.71	125.11	-166.82
	USER-4	835.45	4	291.93	34.94	291.93	0.0
ORIGIN ALL DEST ALL MODE AIR	USER-1	620.31	1	0.0	0.0	0.0	-420.89
	USER-2	680.43	2	60.13	8.84	60.13	-360.77
	USER-3	800.69	3	180.38	22.53	180.38	-240.51
	USER-4	1041.20	4	420.89	40.42	420.89	0.0
ORIGIN ALL DEST ALL MODE RAIL	USER-1	562.59	1	0.0	0.0	0.0	-857.69
	USER-2	685.12	2	122.53	17.88	122.53	-735.17
	USER-3	930.18	3	367.58	39.52	367.58	-490.11

	USER-4	1420.25	4	857.69	60.39	857.69	0.0
ORIGIN ALL DEST ALL MODE ROAD	USER-1	501.74	1	0.0	0.0	0.0	-1497.38
	USER-2	715.65	2	213.91	29.89	213.91	-1283.47
	USER-3	1143.47	3	641.73	56.12	641.73	-855.65
	USER-4	1999.12	4	1497.38	74.90	1497.38	0.0

5. SYSTEMS DESIGN CONSIDERATIONS

5.1 Introduction

This chapter includes a discussion of the design of the system for implementing the new capabilities illustrated as part of this research. Diagrams of the file structures referred to in this discussion appear at the end of the chapter.

5.2 Goal Variable Definition

Coded definitions of goal variables are stored in the ICOM array. The ICOM array has three subscripts. The first subscript I corresponds to the Ith goal fabric. The second subscript J correeponds to the Jth goal variable within the Ith goal fabric. The dictionaries of goal fabric and goal variable names are maintained in the FILDIC and FILDAT arrays. The third subscript in ICOM refers to the goal variable definition codes themselves.

The codes used for operators, data classes, and operand data types are shown in Table 5.1.

The codes assigned to the operands in each data class are shown in Table 5.2.

5.3 Utility Function Definition

Definitions of utility functions are maintained in the UTIL array. Since utility functions currently are limited to linear scoring functions, their definition consists of a column of N values, preceded by a counter indicating the number of values N.

Table 5.1: GOAL VARIABLE DEFINITION CODES

Operators	
Minimum	1
Maximum	2
Average	3
Product	4
Quotient	5
Sum	6
Data Classes	
Link	1
Mode	2
District	3
Interdistrict	4
Operand Data Type Code	
Basic Variable	1
Goal Variable	2
Immediate Data	3

Table 5.2: OPERAND CODES

Link Data Operand Codes	
Vol/Delay Number	1
Number of Lanes	2
Length	3
Passenger Volume	4
Speed	5
Travel Time	6
Mode Type	7
Link Type	8
Capacity	9
Origin Node X Coordinate	10
Origin Node Y Coordinate	11
Destination Node X Coordinate	12
Destination Node Y Coordinate	13
Mode Data Operand Codes	
Subsidy	1
Fixed Cost	2
Variable Cost Rate	3
Tax Rate	4
Accessibility	5
District Data Operand Codes	
Population	1
Per Capita Income	2

Table 5.2 (Continued)

Holding Capacity	3
X Coordinate	4
Y Coordinate	5
Accessibility	6
<u>Interdistrict Data Operand Codes</u>	
Trips	1
Travel Time	2
Fare	3
Frequency of Service	4
Speed	5
Distance	6

5.4 Storage of Evaluation Results

The major task in system design was the establishment of a file to store the results of a series of evaluations. The manipulations and computations performed by the COMPARE GOAL FABRIC command and the WRITE EVALUATION RESULTS command require an evaluation file structure which can be cross-referenced efficiently. The evaluation file has to maintain not only the results of evaluations, but also sufficient information to reconstruct the manner in which the results were generated. Complete identification of a set of results requires specification of the following dimensions:

1 - Goal Fabric Name

2 - Goal Variable Name

3 - Consequence Set Name

4 - Utility Function Name

5 - Range Specification

Since five dimensions are required to specify a particular evaluation result, one possible file structure would consist of a six-dimensional array. One dimension of the array would be used for each dimension of the evaluation results. Dictionaries of goal fabric names, goal variable names, consequence set names, utility function names, and range specification combinations could be searched independently to determine each subscript. The evaluation results would be stored at the sixth level of the array. This type of file structure has two major disadvantages:

1 - The file would tend to be very sparse,

and 2 - References to six-level dynamic arrays in ICETRAN are very time-consuming. (FORTRAN dimensioned arrays will not accommodate 6 subscripts in ICES, which uses the FORTRAN IV E-Level Subset compiler.)

If fewer than five subscripts are used, then two or more dimensions must be associated with a single subscript. Dictionary searches must be performed on combinations of dimensions rather than single dimensions. The advantage of fewer subscripts lies primarily in the reduction in access time required for references to the file structure.

Having considered the tradeoffs between the greater dictionary search times and shorter data access times associated with file structures with fewer subscripts, the evaluation file was designed as three separate arrays with a maximum of three subscripts per array. EVLDIC is a single subscript dictionary array which contains (goal fabric name/consequence set name) <u>pairs</u> which have been used in evaluations. The location in EVLDIC of a particular goal fabric/consequence pair corresponds to the first subs[illegible] two three-subscript arrays, EVLDEF and EVLDAT. The second subscript J in EVLDEF and EVLDAT is associated with a particular (goal variable/utility/range specification) triple. The dictionary of these triples is maintained in the first seven words of the EVLDEF array. Additional information describing the range of evaluation, the data class of the goal variable, and the number of results generated by the evaluation is stored in EVLDEF.

The meaning of range codes IR1, IR2, and IR3 found in EVLDEF depends upon the data class of the goal variable being evaluated. Table 5.3 shows the dimensions assigned to IR1, IR2, and IR3 for each ·a class.

The range codes can assume one of three values: -1, 0, or +1. A -1 indicates that a series of evaluations occurred with the dimension represented by the range code set to EACH of its allowable values. Several evaluation results are generated whenever an EACH specification is used. Evaluation of

'ACCESS' FOR DISTRICTS EACH

will cause the goal variable 'ACCESS' to be evaluated once for each district defined for the consequence set being evaluated. The number of results generated will be equal to the number of districts defined for the action used to generate the consequences.

A 0 value for a range code indicates that evaluation took place over ALL possible values of the dimension represented by the code. Evaluation of

'ACCESS' FOR DISTRICTS ALL

will cause the goal variable 'ACCESS' to be evaluated just once, with all districts considered at one time.

Table 5.3: RANGE CODES

Data Class	IR1	IR2	IR3
Link	'from' node	'to' node	unused
Mode	mode no.	unused	unused
District	district no.	unused	unused
Interdistrict	origin district no.	destination district no.	mode no.

A +1 value for a range code indicates that a single node, mode, or district was specified for that particular dimension. When this is the case, the number[9] of the node, mode, or district is stored as N1, N2, or N3, depending on which range code has a value of +1.

When dictionary searches successfully find the subscript I from EVLDIC and J from EVLDEF, the data can be retrieved directly from EVLDAT. The number of values stored for a given I and J is stored as NVAL in EVLDEF (1,J,8). The location pointed LOC associated with each value in EVLDAT is used to relate the value to the portion of the range of evaluation which was considered when that value was computed.

The MINIMUM and MAXIMUM operators impose another requirement upon the evaluation file. The particular mode, district, link or route for which a minimum or maximum is found may be as important to a decision maker as the value itself. If an evaluation does use either the MINIMUM or MAXIMUM operator, NVAL is stored as a negative number in EVLDEF. The negative value acts as a flag to the WRITE EVALUATION RESULTS command, causing the location at which the value was found to be printed as well as the value itself.

5.5 Goal Fabric Evaluation and Comparison

The two major capabilities implemented during this research effort are the routines for evaluating goal fabrics and comparing the results of the evaluations. Both capabilities employ the same general technique

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[9]The internal number or "machine" number, as opposed to a user-assigned number.

in terms of communication between the Command Definition Language (CDL) programs, which process the user commands, and the ICETRAN programs which perform the file retrieval and computations.[10]

Both evaluation and comparison of goal fabrics are structured as a general command followed by a series of subcommands. The general commands (EVALUATE GOAL FABRIC 'gname' and COMPARE GOAL FABRIC 'gname') simply initialize the computational routines and inform them that goal fabric 'gname' is to be used. Subsequent subcommands perform different tasks which are part of the total computation. The tasks specified by subcommands in the evaluation of a goal fabric are the following:

1. Specify a new utility function
2. Specify a new goal variable to be evaluated

Subcommands in the comparison procedure are used for the following tasks:

1. Specify a base file
2. Specify a set of actions, parameters, consequences, or utilities over which a comparison is to be performed
3. Specify the order in which values of the goal variable are to be ranked
4. Specify the goal variable and range of evaluation whose results are required for the comparison.

Communication between CDL and the ICETRAN routines is accomplished by setting switches in the COMMON area (an area addressable by all

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[10] See reference number 5, ICES Programmers Reference Manual, for a description of the CDL and ICETRAN languages.

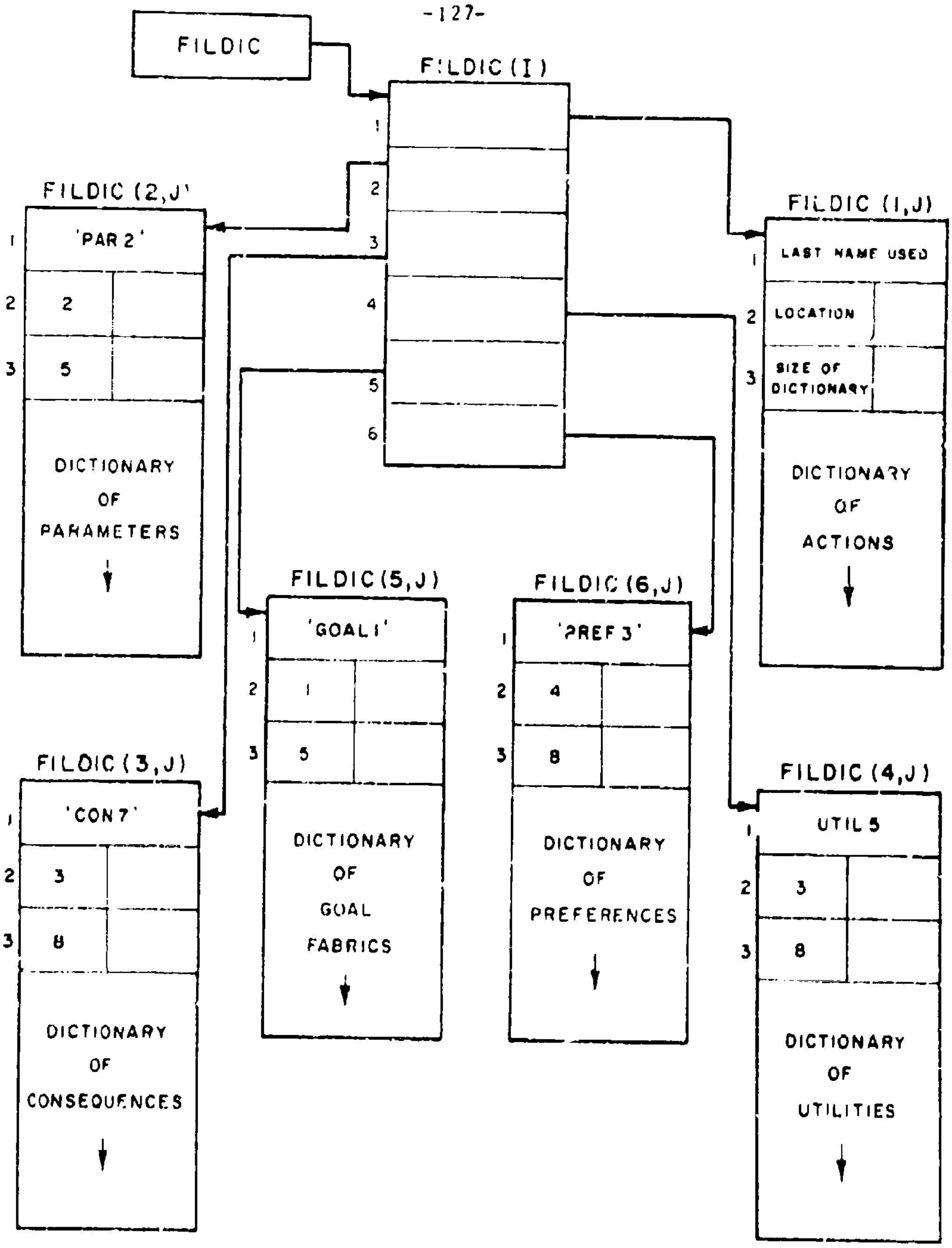
ICETRAN and CDL programs). When a subcommand is processed, a switch is set to an appropriate value and the ICETRAN computational routines are called. The ICETRAN routines examine the switches to determine which subcommand has been given and take the appropriate action.

5.6 Error Checking

Every attempt has been made to detect errors by the analyst when using the new capabilities described here. The frequent communication between CDL and the ICETRAN programs facilitates error checking at intermediate points during the evaluation and comparison procedures.

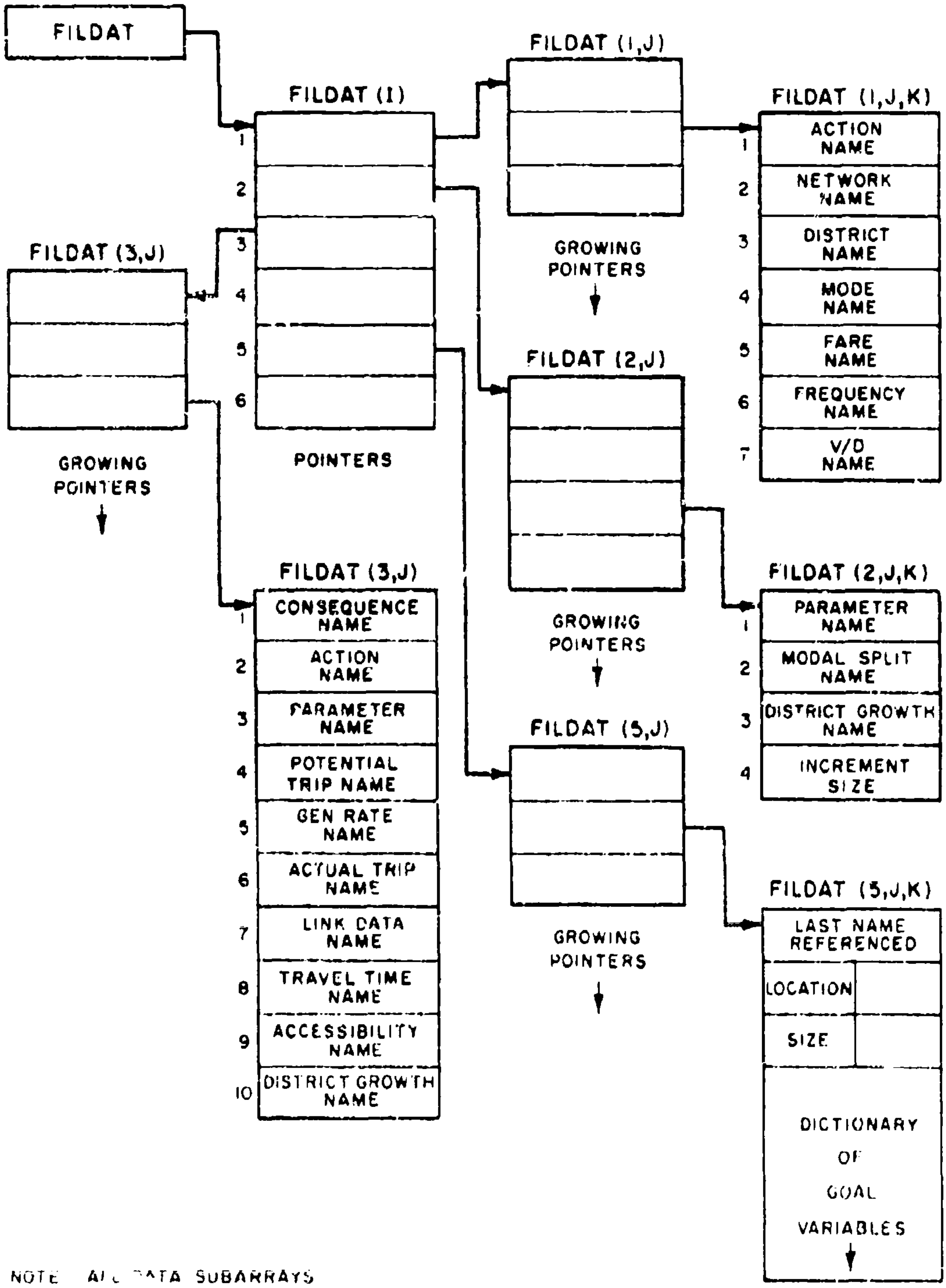
When an error is detected, a message indicating the nature of the error is printed. Subsequent commands which depend upon the successful execution of the command in which an error was found are ignored. Processing is resumed as soon as a command is encountered which does not depend on commands previously processed.

The philosophy of error checking differs for systems designed to operate in a time-sharing computer environment as opposed to a batch processing environment. The analyst using a time-sharing system can correct errors on-line that could not be corrected in a batch processing computer run. Since DODOTRANS operates successfully in both time-sharing and batch processing computer systems, the error checking philosophy used in developing new capabilities is intended to give satisfactory response to users in both environments.



NOTE: ALL SUBARRAYS ARE DOUBLE WORD GROWING ARRAYS

FIGURE 5.1 Dictionary of Data Files



NOTE: ALL DATA SUBARRAYS ARE DOUBLE WORD ARRAYS

FIGURE 5.2: Contents of File Dictionaries

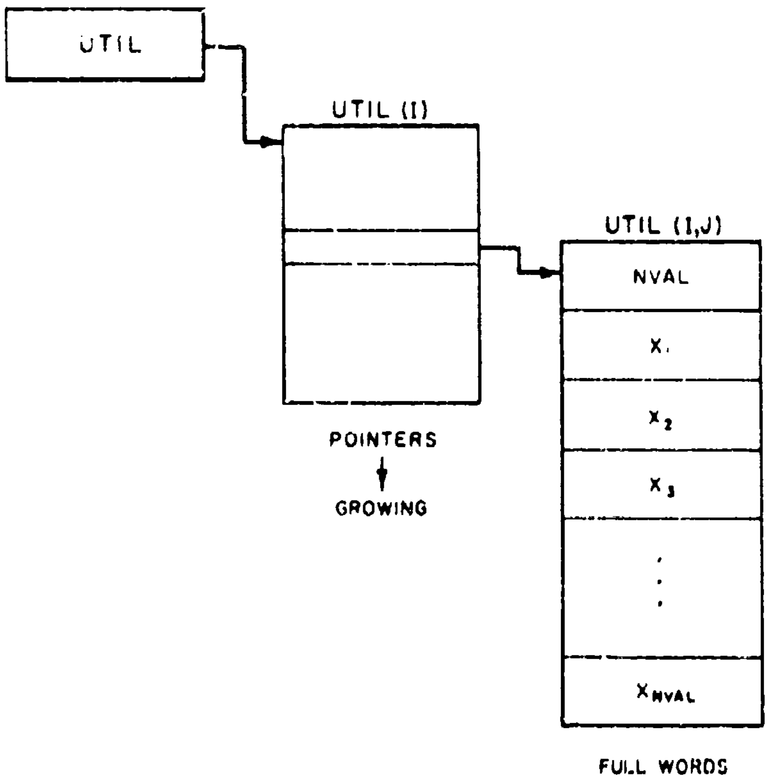


FIGURE 5.3: Utility Function File

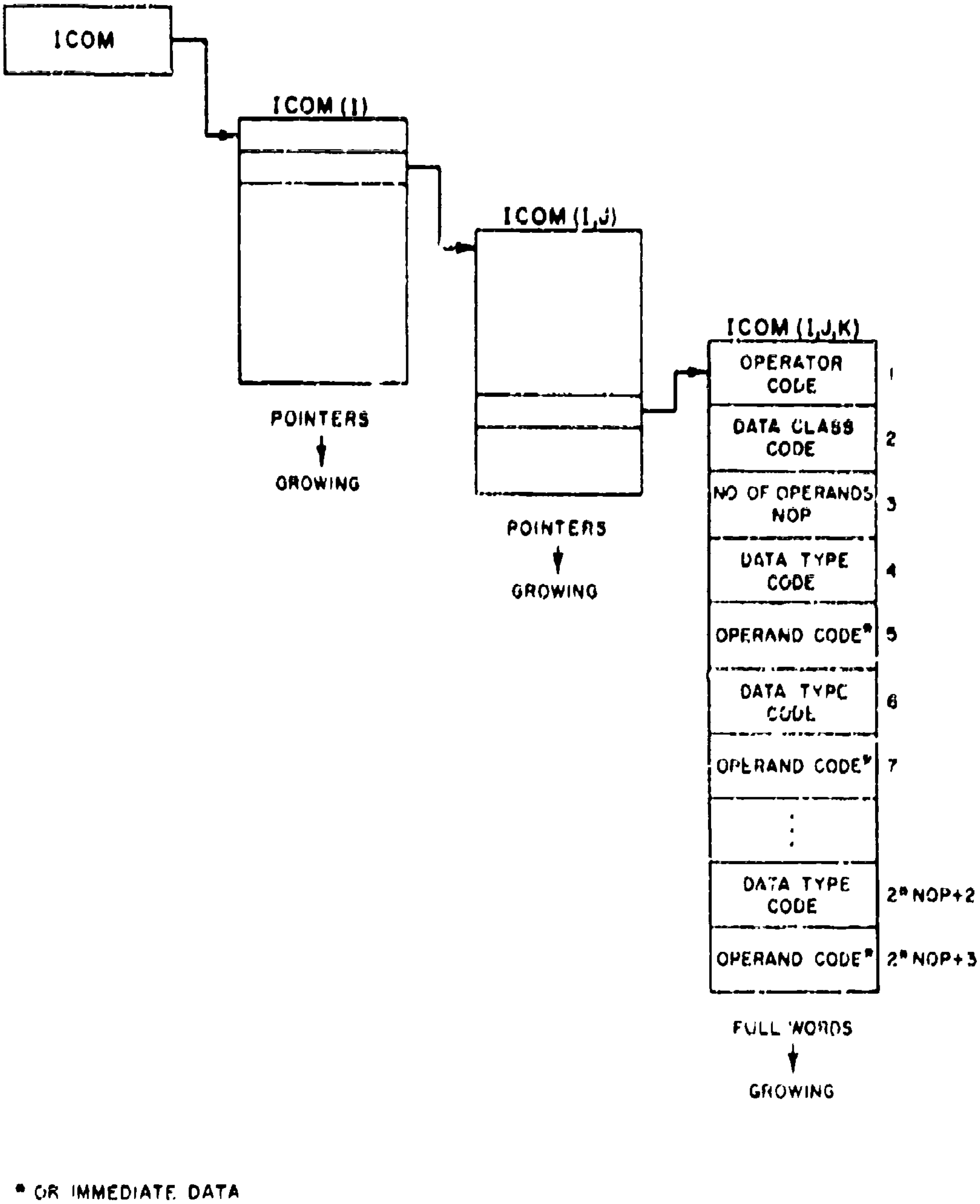


FIGURE 5.4: Goal Variable Definition File

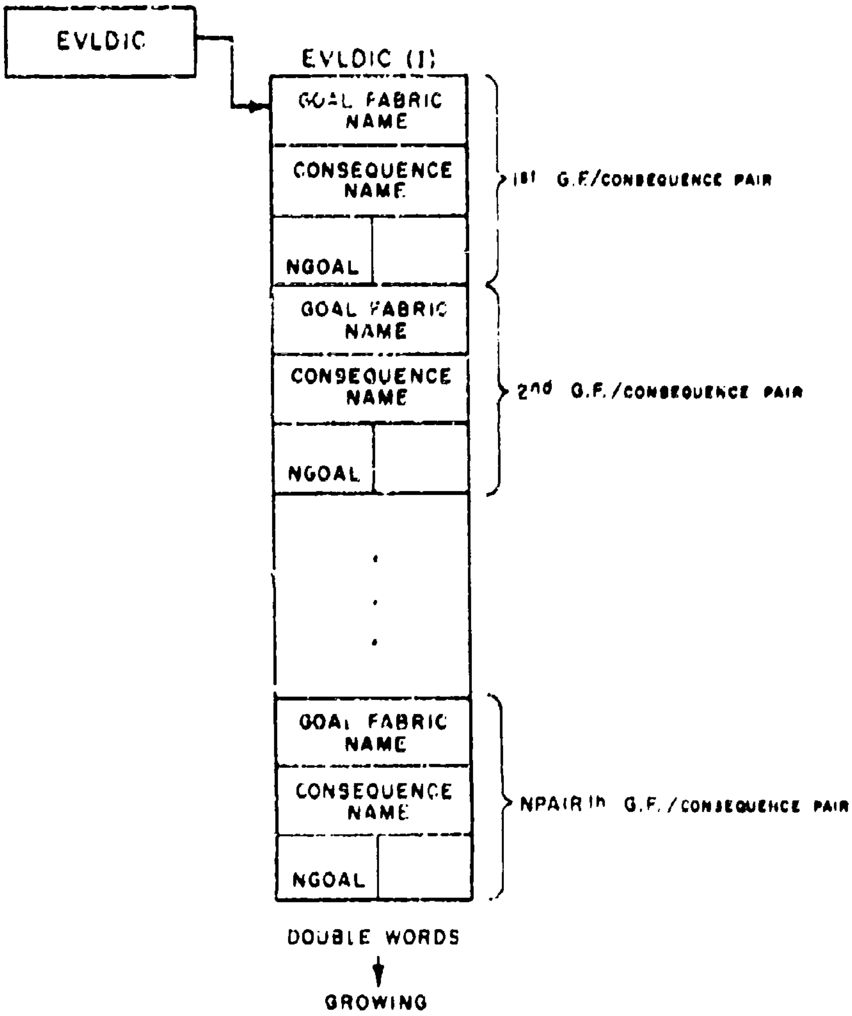


FIGURE 5.5: Dictionary of Evaluations

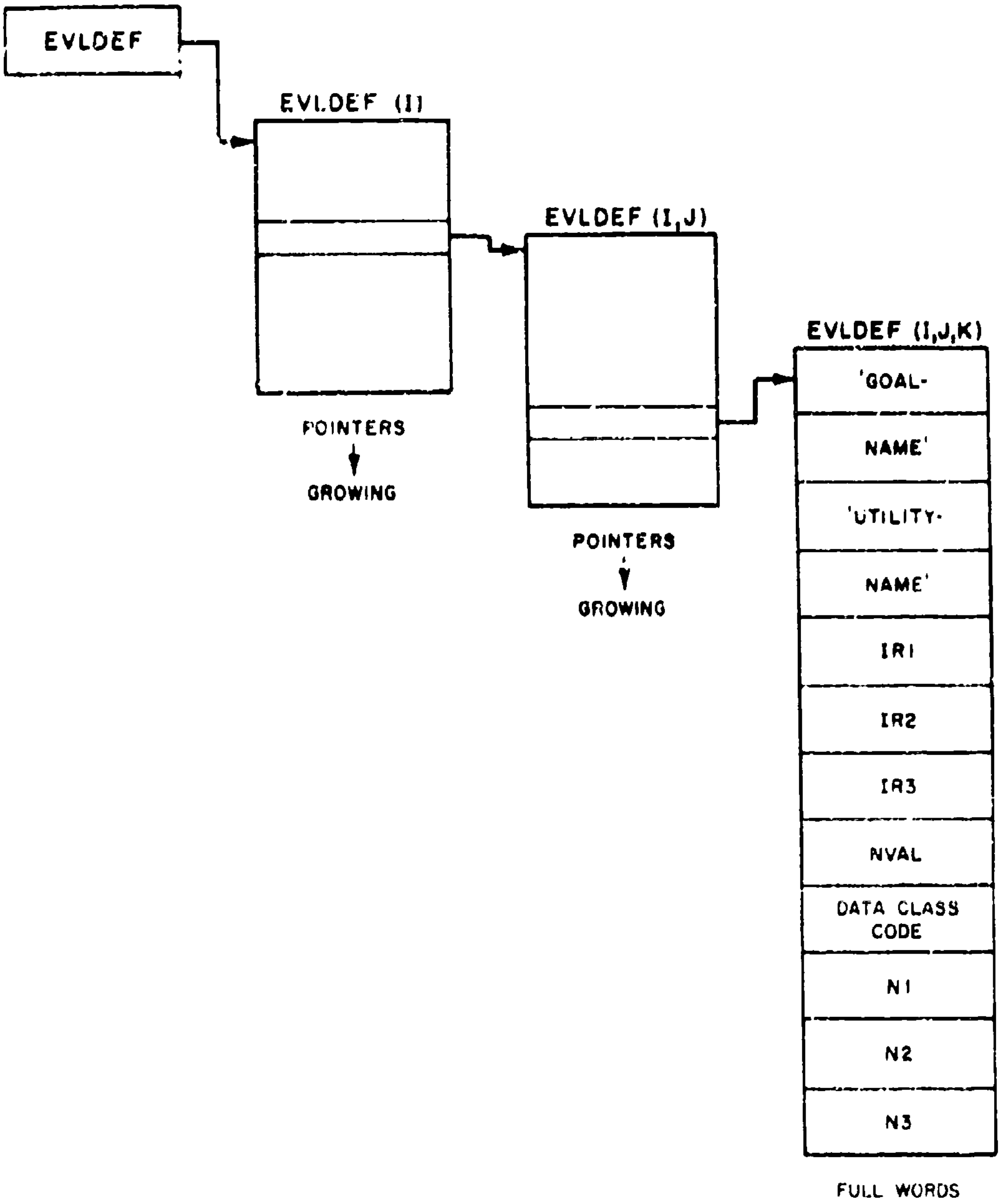


FIGURE 5.6: Evaluation Definition File

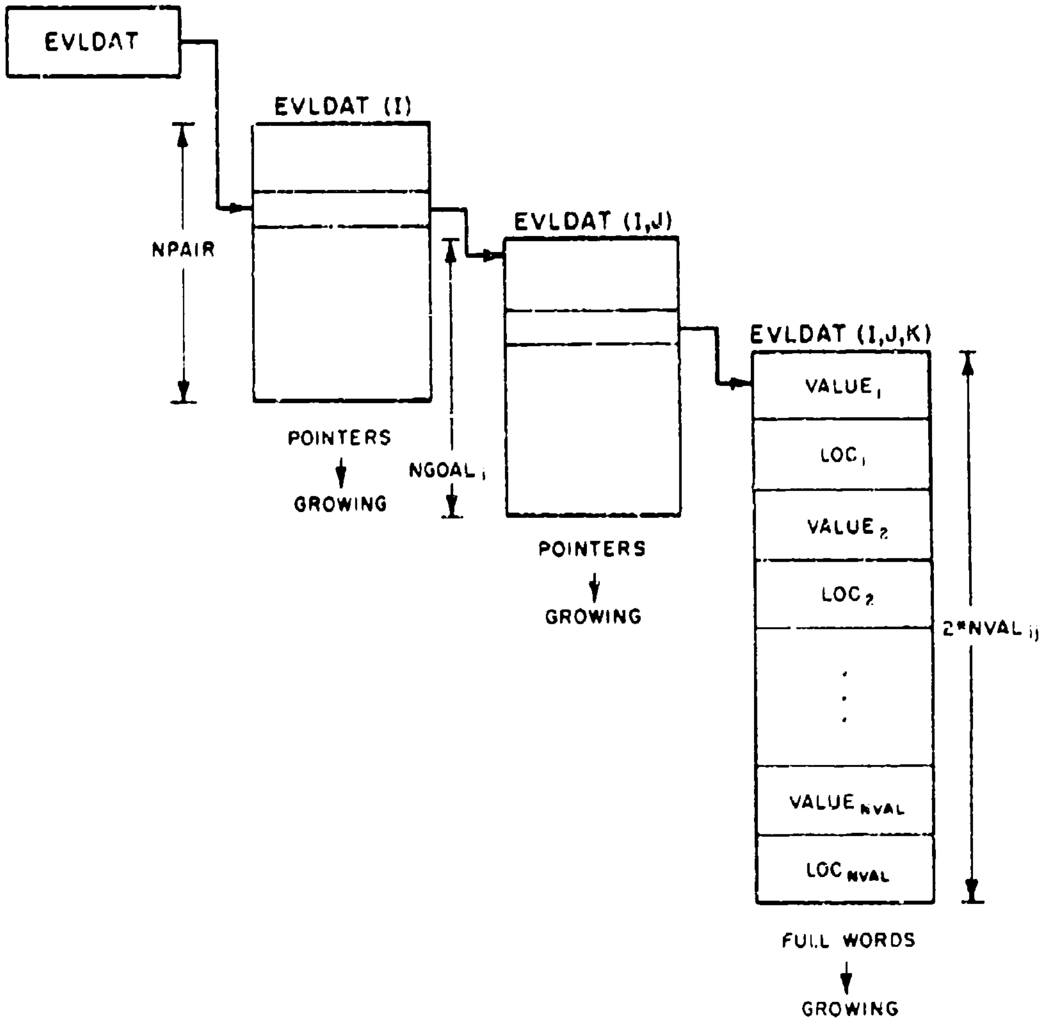


FIGURE 5.7: Evaluation Data File

6. CONCLUSIONS

6.1 Introduction

This chapter contains a discussion of the conclusions that were made on the basis of this research. The conclusions are based upon an evaluation of the effectiveness of the capabilities that have been implemented for the evaluation and comparison of alternative transport systems. Included are recommendations for improvements and extensions to the new capabilities that would enhance their effectiveness as evaluation tools.

6.2 Evaluation of New Capabilities

6.2.1 Goal Fabric Definition

The DODOTRANS user has greater flexibility in the definitions of goal fabrics than did the DODO user. The number of types of basic consequence data available for goal variable definitions has increased from five items in DODO to over 25 items in DODOTRANS. The most useful new data types appear to be the link travel times, speeds, and volumes, and the accessibilities by district and by mode.

The quotient and sum operators also increase the flexibility of the goal variable definition procedure. The sum operator is especially important because it makes possible the definition of a goal variable as a linear scoring function.

6.2.2 Utility Function Definition

Utility functions are necessary components in an evaluation procedure because they provide a method for the analyst to express a

statement of preferences. The capability implemented in this research, namely, a vector of constant utilities which operate upon the operands of a goal variable during evaluation, is the most basic form of utility function. It is exceedingly useful for conducting parametric analyses on the utility of a given impact when a linear scoring function is used to combine several different impacts.

The necessity of defining a utility for all goal variables prior to their evaluation does have one disadvantage. Many goal variables require a utility function with all weights equal to unity. At present the analyst has to define these null utilities. A convention could be defined whereby a special utility function name, e.g. 'UNIT', was made available to the analyst to use whenever a null utility of any dimension was required. This would eliminate the need for the analyst to define these utilities in every analysis.

6.2.3 Goal Fabric Evaluation

The evaluation procedure is essentially the same in DODOTRANS as in DODO with respect to the external command specifications. The differences are 1) a utility function must be specified prior to evaluation of a goal variable, and 2) the range of evaluation has several different forms, depending upon the data class of the goal variable being evaluated.

A significant improvement has been made internally in the evaluation procedure by the addition of an evaluation file which contains the results of all evaluations performed during an analysis. The creation of this file facilitated the development of the comparison procedure.

6.2.4 Goal Fabric Comparison

The goal fabric comparison commands provide the DODOTRANS user with a capability that appeared in a very rudimentary form in DODO. The structure of the command language, consisting of numerous sub-commands preceded by a general command, permits the analyst to establish a number of basic quantities needed for the computation of the comparison results, namely: base data files, a comparison set, and a preferred ranking order. He can then conduct comparisons on the values of a series of goal variables, subject to those base quantities, by specifying only the goal variable name and the range of evaluation. The basic quantities are not specified again for subsequent evaluations unless a change occurs in one of the basic values.

The ability to perform a comparison over sets of actions, parameters, consequences, and utilities facilitates sensitivity analysis on variables which are subject to uncertainty during the prediction and evaluation procedures. In particular, parametric analysis of the demand parameters and the assumed utilities are accomplished in an efficient manner by comparing goal variables over sets of parameters and utilities, respectively.

The comparison of goal variable USERCOST did suggest one manner in which the comparison procedure might be expanded. Noting that the most interesting information obtained from that comparison was a change in the ranking of total user cost by mode as the value of travel time was changed, an extension of the set capability to include sets of modes would facilitate rankings of this type. Similarly, an argument

could be made for the addition of sets of links, districts, and routes to the comparison capability.

6.2.5 Output of Evaluation File

The WRITE EVALUATION RESULTS command was intended to provide a means for the analyst to look at a portion of the evaluation file in a relatively unstructured manner. A simple tabular listing is generated in which the only structure comes from the fact that the results are grouped by goal variable and by utility function. The capability has proved to be more useful than anticipated, however, because it complements the comparison procedure when the goal variable being compared is defined with the maximum or minimum operator. The location of each value, i.e. the specific link, mode, district, or route for which it was found, is not printed as part of the display generated by the compare command when a minimum or maximum goal variable is analyzed. The location is omitted in order to keep the display simple and understandable. If the analyst wishes to know the location of a value or values for a goal variable representing a minimum or maximum, the WRITE EVALUATION RESULTS command provides the capability.

6.2.6 Information Retrieval Routines

The routines for generalized information retrieval added to DODOTRANS as part of this research are useful for several reasons:

1. They extend the definition of goal variables to include link, mode, and district data as well as interdistrict data.
2. They provide access to the data required for the development of a general graphic display capability.

3. They can be used to provide a general interface between the DODOTRANS data files and analytical procedures such as statistical analysis routines.
4. Their modular structure facilitates the addition of new data classes, created by the addition of new models or expansion of existing models, to all of the current evaluation and comparison capabilities.

6.3 Recommendations for Expansion or Modification of New Capabilities

6.3.1 Goal Fabric Definition

The definition of goal fabrics could be improved by expanding the types of operators available for goal variable definitions. The product and quotient operators might be modified to operate upon more than two operands.

$$'goal_1' = A*B*C*D$$
$$'goal_2' = E/F/G$$

A more useful extension would permit combinations of operators to be used in goal variable definitions.

$$'goal_3' = A + B/C - D*E$$
$$'goal_4' = Min[F*G/H]$$

All of the forms of definition noted above could be generated with the existing operators if goal variables were used as operands in the definition of higher-order goal variables. The definition of '$goal_4$' could be generated using existing operators as follows:

$$'goal_5' = F*G$$

$$'goal_6' = ('goal_5')/H$$

$$'goal_4' = Min['goal_6']$$

The goal variable definition and evaluation routines were designed with the knowledge that goal variables might be used as operands in a recursive form of definition in future versions of DODOTRANS. The addition of goal variable operands to the coded definitions of goal variables is a simple task. The major difficulty in implementing the recursive goal variable definition capability is the specification of the range of evaluation for a goal variable operand. Unlike basic operands, the values of goal variable operands are not stored in a file that is referred to by specifying a set of links, modes, districts or routes. Values of goal variables are stored in an evaluation file in which complete identification requires specification of the following items:

1. Goal Fabric
2. Consequence
3. Utility Function
4. Range of Evaluation

Goal variables which use other goal variables as operands cannot be evaluated until a range of evaluation is created which reconciles the specifications listed above with the standard range specifications used for basic operands. In short, goal variable operands represent a new data class. It differs from other data classes in that it is desirable to combine goal variable operands in the same definition with operands from the four original data classes. Combining goal variable operands and basic operands in a single definition requires the specification of a single range of evaluation that will accommodate both operand types.

Regardless of the difficulty of implementation, the recursive goal variable definition capability would greatly increase the power of the goal fabric concept in DODOTRANS.

6.3.2 Utility Function Definition

Several recommendations concerning the definition of utility functions have been suggested by this research. The first concerns the possibility of relieving the analyst of the task of defining unit utility vectors by providing a standard utility which could be specified whenever an n-dimensional unit utility was required (for any value of n).

The constant weights provided by the current capability could be expanded in many ways. The weights might be expanded to include a coefficient and an exponent so that any n-th degree polynomial could be established as a goal variable. A goal variable of the general form

$$\text{'goal}_7\text{'} = \sum_{i=1}^{k} c_i \, [\text{Operand}_i]^{x_i}$$

might be defined using a sum operator and a utility function which include k pairs of weights (c_i, x_i). This form of definition could be implemented with very little modification of the existing programs. The greatest task would be to modify the evaluation routine to include an exponent for each operand in the computation of a goal variable which uses the sum operator.

Another extension of the utility function capability would be to define weights as step functions which assume discrete values over various ranges of the operand being modified. This form would be more difficult to implement than the extended polynomial form outlined above. The evaluation process would have to examine each operand and determine which range its value was in so that a value could be assigned to the utility.

The most general form of utility function would be a user-supplied FORTRAN program which computed the value of a utility given the value of an operand during the evaluation procedure. This form of utility would be the most difficult to use from the user's viewpoint, because he would be required to write and store a FORTRAN routine in a specified manner prior to performing any evaluations with the new utility function. This is true because one cannot interface directly with FORTRAN from an ICES problem-oriented language such as DODOTRANS.

Further analyses should be conducted with the existing utility function capability to determine which functional forms would be most

useful in transport systems analysis before any major software changes are made.

6.3.3 Goal Fabric Evaluation

The evaluation of goal fabrics could be improved if more than one consequence could be specified in the general command. The VTOL example required repetition of the evaluation procedure 11 times whenever new goal variables were evaluated. An optional set name might be specified in the general command which contained the names of several consequences. Goal variables specified with the use of goal variable subcommands would be evaluated for each consequence in the set.

6.3.4 Goal Fabric Comparison

The extension of the comparison set capability to include sets of modes, districts, routes, and links has already been mentioned as a recommendation for further development.

The other extension of the comparison capability which would be of use to the analyst is the option of automatically evaluating a goal variable whenever a value was requested which had not been computed. If this modification were implemented, it should be an option which can be used at the discretion of the analyst. This will provide the analyst with control over the number of evaluations performed during an analysis. The option could be specified as another subcommand during the comparison procedure, similar to the rank order subcommand.

6.3.5 Additional Output Commands

The existing evaluation and comparison capabilities could be improved by the addition of other forms of output. A command which

lists the complete definition of a goal variable or an entire goal fabric would allow an analyst to review the goal variables which he had defined in earlier runs.

Another useful command would list all appearances of a goal variable in an evaluation file. The listing should include the consequence, utility and range specification associated with every appearance of the goal variable in the file.

6.3.6 Disk Storage of Evaluation File

The arrays comprising the evaluation file should be saved along with the rest of the DODOTRANS data structure when the SAVE OPERATION command[11] is used. This must be done so that the results of evaluations performed in one run can be analyzed in subsequent runs.

6.3.7 Specification of the Range of Evaluation

The current goal fabric evaluation and comparison capabilities require that the range of evaluation must be stated each time that a goal variable is evaluated or compared. This requirement stems from the fact that the definition of a goal variable does not include a statement of the range of evaluation. This decision was made because it was noted that a single goal variable, defined as an operator and a number of operands, might be evaluated over many different ranges in the course of an analysis. The goal fabric would contain a great many more goal variables if the definition were extended to include the range of evaluation. It is true, however, that the necessity of specifying the range of evaluation during the evaluation and comparison

[11] See the DODOTRANS Users' Manual

of goal fabrics makes the command language more cumbersome to the analyst. An argument for the inclusion of the range of evaluation in the goal variable definition might be made on this basis. Insufficient use has been made of the existing capabilities to make a firm recommendation for or against this modification. It is mentioned here only to point out the fact that a relative arbitrary design decision was made which may prove to have been unwise as more extensive use is made of the new capabilities.

6.3.8 Shorthand Notation for the Range of Evaluation

A shorthand command notation, similar to the EACH capability, might be implemented which would further reduce the number of commands required to evaluate a goal variable over several ranges. A range specification called EVERY could be defined which would specify that a goal variable was to be evaluated over all possible ranges. For example, the evaluation

'BTLENECK' FOR EVERY RANGE

might compute the same number of results as the commands

```
'BTLENECK' FROM NODES EACH TO NODES EACH
'BTLENECK' FROM NODES ALL TO NODES EACH
'BTLENECK' FROM NODES EACH TO NODES ALL
'BTLENECK' FROM NODES ALL TO NODES ALL
```

Evaluation over <u>every</u> range as defined above requires n^2 commands for a goal variable which has n dimensions to its range. Therefore, use of the EVERY specification with an interdistrict goal variable (3 dimensions) would result in a savings of eight ($n^2 - 1$) commands compared to the current capability. However, before a capability such as EVERY is implemented, it should be determined that the resulting ranges of evaluation are meaningful and useful.

6.3.9 Generalized Graphical Display Capability

The goal variable definition and evaluation routines include a flexible capability for the retrieval and manipulation of a variety of data generated by the DODOTRANS system of predictive models. These information retrieval capabilities could be used for the addition of generalized graphical display capabilities. The greatest single problem in designing <u>general</u> graphics programs is the retrieval of a variety of types of data and conversion of that data into a standard form which can be converted to coordinates for display. The information retrieval routines in DODOTRANS were designed in part to aid in the solution of this problem.

6.3.10 Statistical Analysis of Impact Data

The inclusion of statistical analysis routines such as multiple regression and analysis-of-variance techniques would aid the analyst in recognizing functional relationships and trends in a set of impact data. For example, the frequency of service over a series of routes could be compared with the average travel time over each route for a given mode to see if a well-defined relationship exists between the two

quantities. The tradeoff analyses performed in the Prototype Analysis[12] to determine combinations of fares and frequencies of service which generated a given level of demand could be analyzed with analysis-of-variance methods to see how well the demand could be estimated in terms of fare and frequency of service. The information retrieval routined added to DODOTRANS would facilitate the implementation of other analytical procedures into the evaluation process.

6.4 Summary

The DODOTRANS language is a comprehensive planning tool which permits a user to analyze alternative transport systems. The comparison and evaluation of predicted impacts are integral steps in the analytical process. The research described here has focused upon the extension and improvement of the techniques in DODOTRANS for evaluation and comparison of impacts in an effort to determine the best alternative for implementation in the real world. The evaluation techniques in DODOTRANS do not select the best alternative action for implementation, however. The final decision to accept the best action found thus far or to request the generation of new alternative actions must be the responsibility of the decision-maker alone. The DODOTRANS language is designed to provide a methodology which aids the decision-maker in comparing the performance of several alternative actions with respect to the preferences of relevant actors in the system.

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[12] Ruiter, E. R., A Prototype Analysis

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